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The Nordic Forest Sector Model (NFSM): Data and Model Structure

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Preface

The purpose of this report is to describe the model structure and the data applied in the Nordic Forest Sector Model. The model includes supply of roundwood, processing of industrial roundwood and harvest residues, demand for forest industrial products and trade between regions in the Nordic countries as well as trade between Nordic regions and the rest of the world.

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Ås, December 2016

Walid F. Mustapha

Summary

This report details the data used in NFSM and the model structure. NFSM is a spatial partial equilibrium model developed to assess novel forest-based bio-refinery technologies in the context of the Nordic forest industries and the stationary bio-based energy sector. The model covers forest growth, harvest of roundwood, forest industrial processing, bioenergy production, transport and trade between Nordic regions as well as consumption of forest-based products. Supply of roundwood is determined by industrial demand for roundwood, harvest elasticities and changes in the roundwood growing stock. Industrial production depends on roundwood prices and associated roundwood transport costs, exogenous labour and electricity costs and demand by consumers for industrial products. Similarly, consumer demand is controlled by price elasticities, prices of industrial products and transport costs. Hence, roundwood and product prices are endogenous to the model and are initialized by reference harvest, production, prices, roundwood harvest elasticities and industrial product specific demand elasticities based on econometric studies. The reference year for the model is 2013, but 2012 is applied when data for 2013 was unavailable. The data included in the model comes from a variety of Nordic and international statistical governmental bodies, business reports as well as through interviews.

The model applies recursive optimization – the equilibrium solution and associated endogenous parameters in one period provide the foundation for the period equilibrium in the subsequent period. Hence, the agents operating do not possess any information about the future beyond the current optimization period. Given assumed structural changes in the forest industries, the model is most suitable for model projections 10-20 years into the future.

The data quality applied in the model varies due to representativeness issues and/or uncertainties. Data limitations in large-scale models are unavoidable, and large-scale models are simplified representations of reality. Representativeness issues in the model include aggregation of prices, products, regions, industrial conversion technologies, transport costs, trade and consumption of industrial products. In addition, production inputs and outputs in industrial processing are associated with uncertainty. Data quality issues are discussed throughout the report and any study undertaken with the model should consider data inadequacy since this would depend on the study approach.

Sammendrag

Denne rapporten beskriver data brukt i NFSM samt modell strukturen. NFSM er en romlig partiell likevektsmodell utviklet for å vurdere konkuranseevnen til nye skogsbaserte bio-raffineringsteknologier sett i sammenheng med den nordiske skogsindustri og den stasjonære biobaserte energisektoren. Modellen dekker skogvekst, hogst av tømmer, bearbeiding av tømmer i skogsindustrien, transport/handel mellom nordiske regioner og til/fra nordiske lander til utlandet, samt endelig forbruk av produkter produsert i skogsindustrien. Tømmertilbudet bestemmes av industriell etterspørsel etter tømmer, tilbudselastisiteter og endringer i det stående volumet. Industriproduksjonen er avhengig av tømmerpriser og tilhørende tømmertransportkostnader, eksogene kostnader på arbeidskraft og strøm og forbrukeretterspørsel etter industriprodukter. Forbrukernes etterspørsel etter produkter bestemmes av priselastisiteter, prisene på industrielle produkter og transportkostnader. Tømmer- og produktpriser er endogene i modellen med utgangspunkt i basisårverdier for avvirkning, produksjon, forbruk, priser og elastisiteter. Tilbudselastisiteter på tømmer og industrielle produktspesifikke etterspørselselastisiteter som er basert på økonometriske studier, definerer endringen i etterspørselen. Basisåret for modellen er 2013, men 2012 er brukt i tilfeller hvor 2013 data var utilgjengelig. Dataene som inngår i modellen kommer fra en rekke nordiske og internasjonale statlige statistiske organer, via virksomhetsrapporter og igjennom intervjuer.

Modellen anvender rekursiv optimalisering – likevekt i en periode danner sammen med endringer i eksogene parametre grunnlaget for likevekt i den neste perioden. Aktørene har i modellen ingen informasjon om fremtiden, men tilpasser forbruk, produksjon og investeringer ut fra informasjonen i inneværende periode. Ettersom det forekommer større strukturelle endringer i skogsindustrien og bioenergisektoren, passer modellen i utgangspunktet best til analyser 10-20 år inn i fremtiden.

Kvaliteten på dataene i modellen varierer på grunn av representativitetsaspekter og/eller usikkerhet. Slike modeller er også en forenklet representasjoner av virkeligheten. Representativitetsbegrensninger i data og modell inkluderer aggregering av priser, produkter, regioner, industrielle konverteringsteknologier, transportkostnader, handel og forbruk av industriprodukter. I tillegg er innsatsfaktorer i industriell foredling forbundet med usikkerhet. Datakvaliteten er diskutert igjennom hele rapporten og fremtidige analyser foretatt med modellen bør ta høyde for usikkerhet i datagrunnlaget. Betydningen av dette avhenger av type analyse.

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1 INTRODUCTION

This report provides an overview over the data employed in the Nordic Forest Sector Model (NFSM) and the model specifications. NFSM is a spatial partial equilibrium model and includes forest growth modelling, harvest of roundwood, collection of harvest residues, wood processing in forest industries, production of bioenergy, investment in bio-refineries, demand for wood-based products and regional/transnational trade to/from regions in Denmark, Finland, Norway and Sweden. The reference year for the model is 2013 for all countries, but 2012 data is also used in cases where 2013 data is unavailable. The model is dynamic in that it can cover several time instances – it is most suited for projections 10-20 years into the future. Recursive optimization is applied in the model for solving the objective function; the objective function is solved for one period (which corresponds to one year), parameter values are updated based on the equilibrium solution and are fed into the objective function for subsequent solving in the following period. Hence, agents in the model are non-anticipative, meaning that they possess no information about the future. The prices of roundwood and wood-based products are endogenous to the model; they depend on demand and econometrically specified supply and demand elasticities, respectively. NFSM applies the same principles as the Global Trade Model (GTM) (M. Kallio, Dykstra, & Binkley, 1987) and is similar in structure to the Global Forest Sector Model (EFI-GTM) (A. M. I. Kallio, Moiseyev, & Solberg, 2004), and especially the Norwegian Forest Sector Model (NTMIII) (Trømborg & Sjølie, 2011). The main structural changes compared to NTMIII is the introduction of an endogenous bio-refinery investment module, the inclusion of elastic labour costs and the application of a piecewise linear approximation routine on the original nonlinear objective function terms.

The model components can be categorized into five distinct categories. (1) *Roundwood supply*, (2) *Industrial production*, (3) *Consumption of forest industrial products*, (4) *Bio-refinery investment* and (5) *Transport and trade*. (1) Forest-owner harvest behaviour is modelled by applying regional roundwood supply curves using supply elasticities. The level of the roundwood supply curves is determined by reference roundwood prices and quantities, whereas the price elasticities determine how the supplied volume changes when the price of the given roundwood supply assortment in the given region changes. Changes in growing stocks occur subsequent to harvest and growth of the stock. The volume elasticity determines the shift in roundwood supply for the given change in growing stock. This occurs once for each objective function solution at an annual interval. (2) Industrial production is modelled by activity level in an input/output table. Input coefficients determine the level of inputs needed for producing one unit of output. The level of production is determined by endogenous regional roundwood prices, endogenous output prices and interregional transport costs for final products. The prices of labour and energy are given exogenously. However, labour costs for sawnwood processing are modelled incrementally using a nonlinear trajectory, as mentioned above. The production level in each mill is decided by marginal cost and marginal revenue given by the market prices; it is assumed that profit is maximized when marginal cost equals marginal revenue. (3) On the demand side, consumers maximize their welfare with consumption of the forest industry products. Consumer demand for forest industry products is modelled using a linear function, where econometric estimates are used for the defined price elasticity for each product in a given region that defines how much demand decreases with increasing forest industry product price. The initial demand level is determined by observed prices and quantities in the reference year. Demand is subject to annual updating following a predetermined projected GDP growth and GDP elasticities. (4) Investment in bio-refineries is determined by annualized investment capital expenditures as well as the industrial production equilibrium associated production. The investment costs for bio-refineries decrease with technology learning and scaling factors. (5) Trade occurs in the model when price differences of a product in two given regions surpass the transport costs between the regions. Figure 1 displays the components in the model.

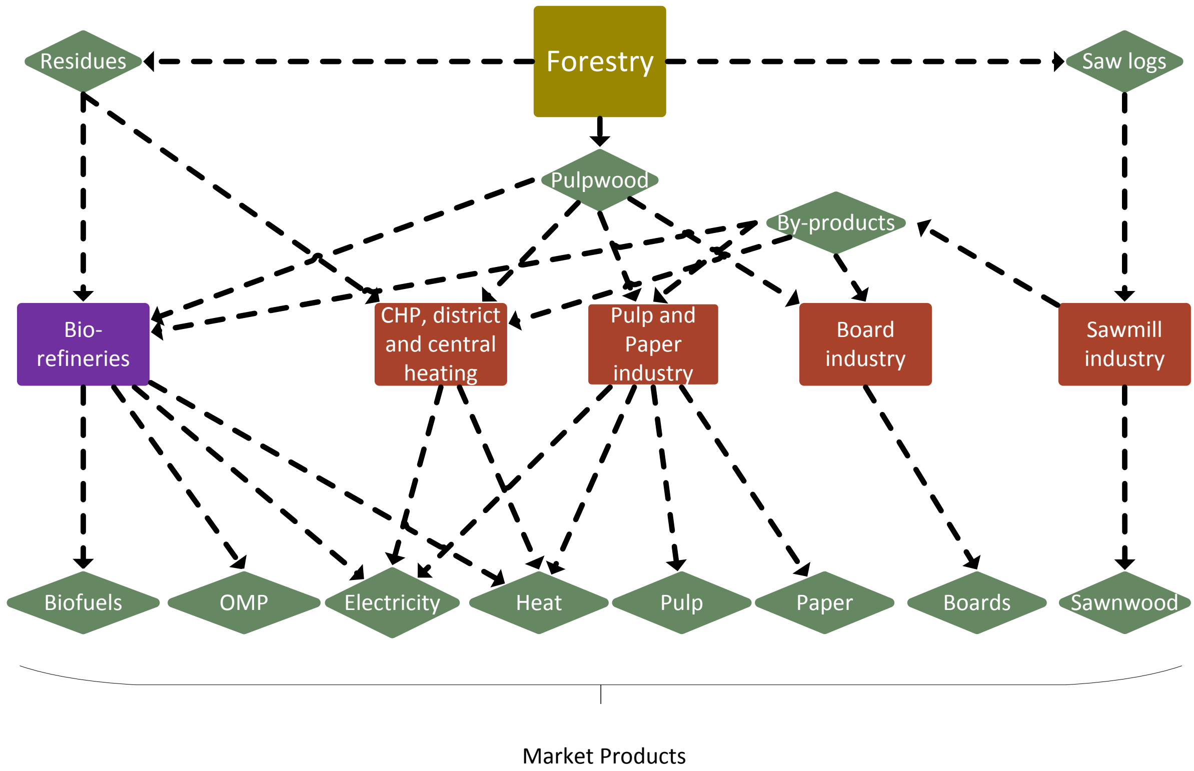

Figure 1. Supply flows in NFSM. OMP = other market products.

2 MODEL SPECIFICATIONS

As mentioned in the introduction, forest sector models such as the GTM (M. Kallio et al., 1987), EFI-GTM (A. M. I. Kallio et al., 2004) and NTMIII (Trømborg & Sjølie, 2011) contain nonlinear terms in the objective function. Hence, the objective function is solved as a nonlinear programming (NLP) problem. The nonlinear terms include the integrated demand curves, the roundwood supply curves and the integrated harvest-residue supply curves (in the case of NTMIII). In practice, the nonlinearity of the objective function restricts the use of binary variables. Binary variables are mandatory components for specifying investment modules with discrete capacities – they are needed to specify minimum capacity installation size to avoid unrealistically small investments. One approach is to change the formulation from NLP to Mixed Integer Nonlinear Programming (MINLP). This maintains the nonlinearity of the objective function terms and permits the inclusion of binary variables. However, MINLP optimization problem solutions have not reached the maturity and reliability achieved by linear, integer and NLP problems (GAMS Development Corporation, 2013) and are not suitable for large-scale models (Polisetty & Gatzke, 2005), such as NFSM, which has over 170000 single variables when formulated as a MINLP model. A more suitable approach for large-scale models, such as NFSM, is the application of a piecewise linear approximation routine. An NLP problem can be approximated as a Mixed Integer Programming (MIP) by fitting a sequence of linear segments to a nonlinear function, which is solvable with linear programming methods (Bradley, Hax, & Magnanti, 1977). With the application of the piecewise linear approximation routine to the nonlinear terms of the original model structure (A. M. I. Kallio et al., 2004), as well as the introduction of new terms, the objective function to maximize for a single period becomes:

$$\begin{aligned} &\sum_{if}\sum_{n=1}^{N} CON_{ifn} - \sum_{iw}\sum_{n=1}^{N} HARV_{iwn} - \sum_{iu}\sum_{n=1}^{N} HRES_{iun} - \sum_{il} C_{il}CF_{il}PR_{il} \\ &\quad - \sum_{is}\sum_{m=1}^{M} SL_{isn} - AN\sum_{ib}\sum_{n=1}^{N} INV_{ibn} - \sum_{ijk} TC_{ijk}TQ_{ijk} \end{aligned} \tag{2.1}$$

The indexes i and j refer to regions, f to consumer products, w to roundwood categories, u to harvest residues, b to bio-refinery technologies and k to all products (consumer products, intermediate products, roundwood and harvest residues). l refers to production activities excluding sawnwood labour input and costs which is handled by s. n ($n \in 1,2,\dots,N$) and m ($m \in 1,2,\dots,M$) are the numbers of piecewise linear segments, where N is different from M. CON_{ifn} (Term 1) is the piecewise linear approximation of the inverse demand function (2.2) for consumer product f in region i.

$HARV_{iwn}$ (Term 2) represents the piecewise linear approximation of the inverse roundwood supply function (2.5) for roundwood w in region i. $HRES_{iun}$ (Term 3) approximates the integral of the harvest residue supply function (**2.9**) for residue u in region i. C_{il} is the exogenous cost of input in production, CF_{il} is the technology specific input coefficient while PR_{il} is the production output variable for activity l in region i. SL_{isn} (Term 5) and INV_{ibn} (Term 6) are the linear approximations. SL_{isn} applies to labour cost function (**2.10**) for cost s in region i while INV_{ibn} applies to the bio-refinery investment function (**2.11**) for bio-refinery technology b in region i. AN is the annuity factor for the bio-refinery technology investments. TC_{ijk} is the transport cost while TQ_{ijk} is the transport variable for product k from region i to region j.

$$\sum_{n=1}^{N} CON_{ifn} \approx \int_{0}^{Q_{if}} (\alpha_{if} + \beta_{if} Q_{if}) dQ_{if} \tag{2.2}$$

The function on the right-hand side of (**2.2**) is the inverse demand for final products f in region i. The integral of the function returns the area under the demand curve. Here Q_{if} is the demand variable while α_{if} (**2.3**) and β_{if} (**2.4**) are estimated parameters.

$$\alpha_{if} = \widehat{PP}_{if} - \frac{\widehat{PP}_{if}}{E_{if}} \tag{2.3}$$

$$\beta_{if} = \frac{\widehat{PP}_{if}}{(\hat{Q}_{if} E_{if})} \tag{2.4}$$

$\widehat{PP}_{if}$ is the reference product price, E_{if} is the demand elasticity with regard to the price and $\hat{Q}_{if}$ of the reference quantity demanded. At time t, α_{if} and β_{if} are updated via (**2.3**) and (**2.4**), respectively, using the periodic solution parameters PP_{if} and Q_{if} from time $t-1$.

$$\sum_{n=1}^{N} HARV_{iwn} \approx \int_{0}^{H_{iw}} (\gamma_{iw} H_{iw}^{\zeta_{iw}}) dH_{iw} \tag{2.5}$$

The function on the right-hand side in (**2.5**) is the inverse supply function for roundwood w in region i while the right-hand side is the linear approximation (Term 2) in (2.1). The integral of the function returns the area under the roundwood supply curve. γ_{iw} is an estimated parameter, H_{iw} is the harvest level variable and ζ_{iw} is the econometrically estimated roundwood supply elasticity.

$$\gamma_{iw} = \frac{\widehat{RP}_{iw}}{\widehat{H}_{iw}^{\zeta_{iw}}} \tag{2.6}$$

$$\gamma_{iw,t} = \frac{\gamma_{iw,t-1}}{\left(\frac{G_{iw,t}}{G_{iw,t-1}}\right)^{\zeta_{iw}}} \tag{2.7}$$

γ_{iw} is estimated differently for the reference year (**2.6**) and for subsequent simulation years (**2.7**). Where $\widehat{RP}_{iw}$ is the roundwood reference price and $\widehat{H}_{iw}$ is the reference harvest level. The parameter γ_{iw} is updated following the objective function maximization. At time t, γ_{iw} is updated based on γ_{iw} at time $t-1$, the growing stock G_{iw} at times t and $t-1$ and the roundwood supply elasticity.

$$G_{iw} = (1 + GR_{iw})G_{iw,t-1} - H_{iw,t-1} \tag{2.8}$$

The growing stock G_{iw} (**2.8**) changes in each period according to the growth rate GR_{iw} as well as the harvest level and growing stock in the previous period (Torjus F. Bolkesjø, Trømborg, & Solberg, 2005).

$$\sum_{n=1}^{N} HRES_{iun} \approx \int_{o}^{R_{iw}} (\eta_{iu} + \theta_{iu}R_{iu})dR_{iu} \tag{2.9}$$

The function on the right-hand side in (**2.9**) is the inverse supply for harvest residues for residue u in region i. The integral of the function returns the area under the harvest-residue supply curve. η_{iu} and θ_{iu} are exogenous parameters (Carlsson, 2012; Rørstad, Trømborg, Bergseng, & Solberg, 2010; Routa, Asikainen, Bjorheden, Laitila, & Roser, 2013; Trømborg & Sjølie, 2011) and R_{iu} is the harvest residue supply variable.

$$\sum_{m=1}^{M} SL_{isn} \approx \vartheta_{is}\left(\frac{PR_{is}}{\widehat{PR}_{is}}\right) + \kappa_{is}\left(\frac{PR_{is}}{\widehat{PR}_{is}}\right)^{2} \tag{2.10}$$

The right-hand side of (**2.10**) displays the sawnwood labour cost function for sawnwood technology s in region i. ϑ_{is} and κ_{is} are parameters estimated based on national labour costs (Eurostat, 2013b) as well as technology specific input coefficients. $\widehat{PR}_{is}$ is the production level at the reference year.

$$\sum_{n=1}^{N} INV_{ibn} \approx \hat{\lambda}_{ib}\left(\frac{BR_{ib}}{\widehat{BR}_{ib}}\right)^{\mu_{ib}} \tag{2.11}$$

(2.11) shows the investment function for bio-refinery technologies. The left-hand side displays the piecewise linear approximation while the right-hand side displays the actual function for bio-refinery technology b in region i. $\hat{\lambda}_{ib}$ is the reference capital expenditure at reference capacity $\widehat{BR}_{ib}$. BR_{ib} is the investment variable and μ_{ib} is an exogenous parameter covering investment cost reductions associated with economies-of-scale and learning-by-doing.

The objective function is subject to the following constraints:

$$Q_{if} - \sum_{l} CF_{fl} PR_{il} + \sum_{j} \left(TQ_{ijf} - TQ_{jif}\right) \quad \forall f, i \tag{2.12}$$

$$-\sum_{l} CF_{al} PR_{il} + \sum_{j} \left(TQ_{ija} - TQ_{jia}\right) \quad \forall a, i \tag{2.13}$$

$$-H_{iw} - \sum_{l} CF_{wl} PR_{il} + \sum_{j} \left(TQ_{ijw} - TQ_{jiw}\right) \quad \forall w, i \tag{2.14}$$

$$PR_{iz} \leq CAP_{iz} \tag{2.15}$$

$$\sum_{il} CF_{rl} PR_{il} \leq \sum_{if} \left(v_{if} Q_{if}\right) \tag{2.16}$$

$$BR_{ib} \geq BC_b \tag{2.17}$$

$$Q_{if}, H_{iw}, R_{iu}, PR_{il}, BR_{ib}, TQ_{ijk} \geq 0 \quad \forall i, j, k. \tag{2.18}$$

(2.12) ensures that consumption of final products is equal to the difference between production and net export in each region. Similar to (2.12), (2.13) and (2.14) balance regional use of intermediate products and roundwood. A similar equation exists for harvest residues (where the set w is replaced by the set u in (2.14). For pulp and paper, production cannot exceed capacity (2.15), where CAP_{iz} is the capacity of pulp and paper production activity z in region i. (2.16) restricts the use of recycled paper in production to a predetermined recycle rate share v_{if} of the total paper consumption of final product f in region i, where r represents the recycled paper grades. Bio-refinery investment minimum-capacities are ensured through (2.17), where BC_b is a technology-specific minimum capacity. Finally, (2.18) provisions non-negativity constraints on consumption, harvest, harvest residues, production, bio-refinery investment and trade. The model is solved as a MIP problem with the CPLEX solver using the General Algebraic Modelling System (GAMS).

3 PRODUCTS AND REGIONS

Table 1 displays the 6 roundwood assortments, the 12 intermediate and 11 final products included in the model. Biofuels and other bio-refinery products are not listed here since these differ depending on the application of the model. Due to data availability issues, a simplified approach to model the products in the forest industries is applied. An aggregation of a multitude of paper grades into four aggregate products is one of these simplifications.

Table 1. Roundwood assortments, intermediate and final products in the model.

Roundwood [m^3]	**By-products**	**Sawnwood** [m^3]	**Boards**	**Pulp and paper** [tonnes]	**Bioenergy for market** [MWh]
Spruce pulpwood	Harvest residues (MWh)	Spruce sawnwood	Fibreboard (tonnes)	Mechanical pulp	Space heating-households (Bioheat)
Spruce sawlogs	Sawdust (tonnes)	Pine sawnwood	Particle board (m^3)	CTMP	Local heating central (Bioheat)
Pine pulpwood	Shavings (tonnes)	Non-coniferous sawnwood	Plywood (m^3)	Sulphate pulp	District heating (Bioheat)
Pine sawlogs	Bark (m^3)			Sulphite and dissolving pulp	CHP heating (Bioheat)
Non-coniferous pulpwood	Firewood (m^3)			Newsprint	
Non-coniferous sawlogs	Chips (m^3)			Printing and writing paper	
	Pellets (tonnes)			Liner/Case materials	
				Other paper and board	
				Recycled paper	

The regionalization of Denmark, Finland, Norway and Sweden is based on the resolution of available data and proximity of countries. 10 regions within each country consist of 1-3 counties except for Denmark, which is modelled as a single region. Table 2 below shows region names and which counties they represent. In order to account for trade between the Nordic countries and other countries an additional region representing the "rest of the world" is included. Figure 2 displays the regions on map.

Table 2. Region names and counties they represent.

Region label	Region
A1	Rest of the world
D1	Denmark
F1	Lappi
F2	Oulo - Pohjois-Suomi, Pohjois-pohjanmaa, kainuu
F3	Vaasa - Kaski-pojhanmaa, Etela-Pohjanmaa, Pohjanmaa
F4	Keski-Suomi
F5	Kuopio - Pohjois-Savo
F6	Pohjois-Karjala
F7	Turku Ja Pori - Satakunta, Ahvenanmaa
F8	Hame - Pirkanmaa
F9	Mikkeli - Etela-Savo
F10	Uisimaa
N1	Østfold
N2	Akershus, Oslo
N3	Hedmark
N4	Oppland
N5	Vestfold, Buskerud
N6	Aust-Agder, Telemark
N7	Rogaland, Vest-Agder
N8	Sogn og Fjordane, Hordaland
N9	Sør-Trøndelag, Møre og Romsdal
N10	Nordland, Nord-Trøndelag, Troms, Finnmark
S1	Norrbotten
S2	Vasterbotten
S3	Jamtland
S4	Vasternorrland
S5	Gavleborg, Dalarna
S6	Uppsala, Stockholm, Sodermanland, Vastmanland
S7	Varmland, Orebro
S8	Vastre Gotaland
S9	Ostergotland, Jonkoping, Kalmar, Gotland
S10	Halland, Kronoberg, Blekinge, Skane

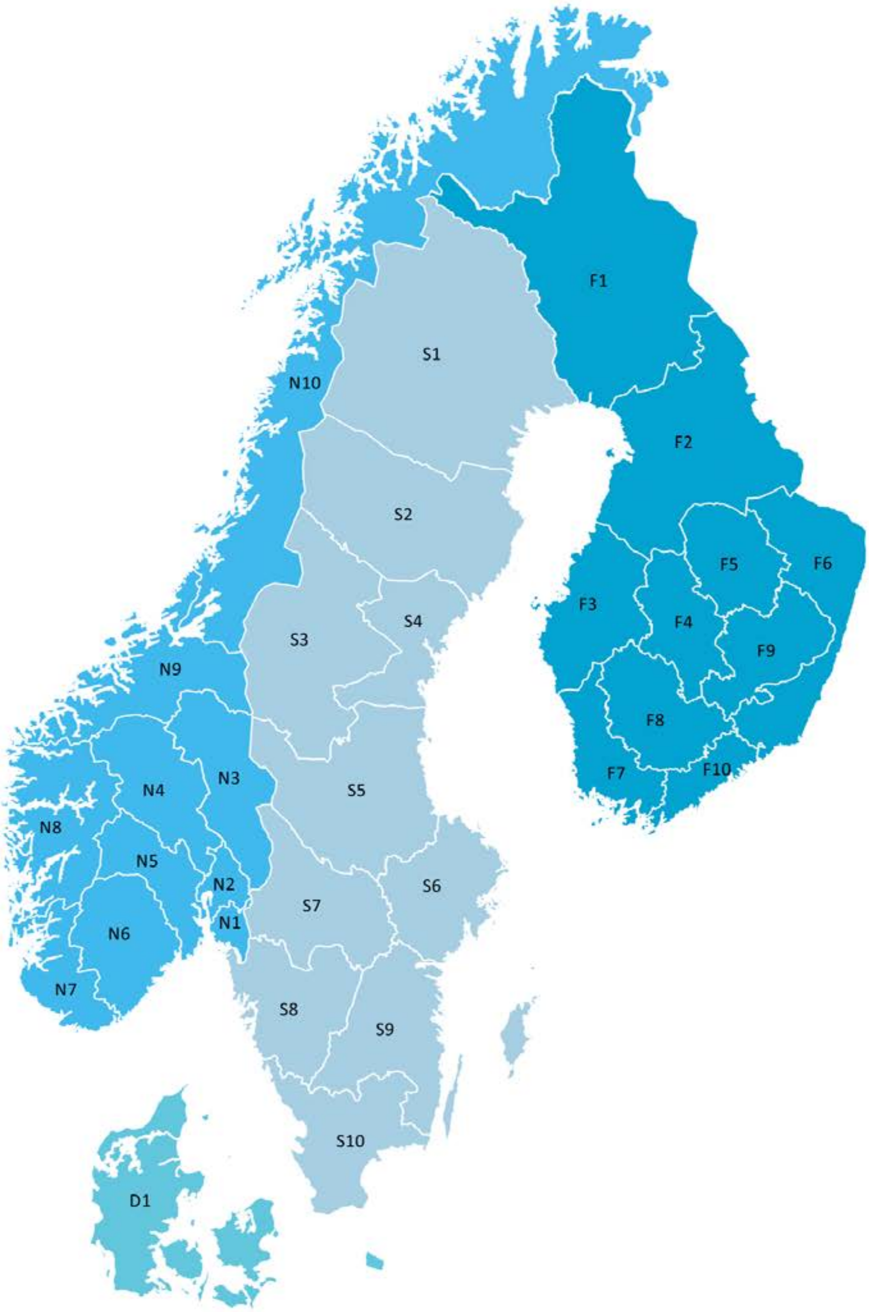

Figure 2. Regions in NFSM. Region names are defined in Table 2.

4 BIOMASS SUPPLY

4.1 HARVEST, STANDING VOLUME AND INCREMENT

Table 3 shows the harvest levels of the assortments used in the model. The harvest data for Finland and Norway is provided in m^3 and it is assumed that bark constitutes 15 % in order to define under bark (ub) volumes. The Swedish harvest data was available in two formats at national and regional scale. No distinction was made between assortments in the regional harvest data but only at national scale. As an approximation, it is assumed that national assortment data (use of roundwood in the pulp and sawnwood industry) is representative of regional harvest. In addition, no distinction was made between species at regional scale. In order to determine the harvest level of spruce and pine, the total harvest of coniferous species is assumed to follow the same proportions as the growing stock in the region. Because of the uncertainty associated with the regional species and assortment harvest levels, harvest levels are altered moderately before the calibration of the model but subsequent to the determination of regional assortment and species needs for regional production while also taking into account the national trade balances.

Table 3. Harvest of industrial roundwood in 2013 for Denmark (Statistics Denmark, 2013), 2013 for Sweden (Swedish Forest Agency, 2014), 2012 for Finland (METLA, 2013) and 2012 for Norway (Statistics Norway, 2013a).

	Spruce sawlogs	Pine sawlogs	Non-coniferous sawlogs	Spruce pulpwood	Pine pulpwood	Non-coniferous pulpwood	TOTAL
				1000 [m^3 ub]			
D1	2,102	233	126	362	6	1,686	4,514
F1	752	325	0	1,269	240	378	2,965
F2	320	2,360	0	469	1,729	1,468	6,346
F3	130	230	10	1,768	2,246	361	4,746
F4	437	449	232	276	1,073	790	3,257
F5	682	220	34	431	119	1,220	2,706
F6	2,255	2,549	122	4,926	5,707	1,236	16,796
F7	1,497	991	27	125	1,388	173	4,201
F8	2,195	1,466	98	49	73	331	4,213
F9	1,633	628	221	0	0	1,015	3,496
F10	1,459	249	278	604	1,380	220	4,189
N1	3,315	131	2	599	12	0	4,059
N2	314	177	3	206	2	0	702
N3	151	155	171	273	12	0	762
N4	575	177	0	890	13	0	1,655
N5	133	103	4	64	0	0	304
N6	125	198	0	242	0	2	567
N7	336	18	1	0	94	8	456
N8	35	0	0	0	0	0	35
N9	33	22	2	22	8	0	87
N10	293	0	1	649	0	1	944
S1	358	1,372	1	1,737	1,074	152	4,694
S2	1,667	1,258	1	505	40	923	4,393
S3	895	767	0	196	43	267	2,168
S4	1,438	1,266	1	2,561	2,414	368	8,047
S5	1,718	3,776	27	3,570	1,545	1,203	11,839
S6	2,143	1,443	1	2,065	1,305	764	7,721
S7	2,008	1,462	1	3,840	2,438	1,370	11,120
S8	1,387	823	12	547	876	88	3,734
S9	1,573	1,692	1	2,426	1,861	1,061	8,615
S10	3,145	1,234	1	2,241	1,229	841	8,691
Total DK	2,102	233	126	362	6	1,686	4,514
Total FI	11,360	9,466	1022	9,918	13,955	7,192	52,914
Total NO	5,310	981	183	2,944	141	11	9,570
Total SW	16,333	15,092	46	19,688	12,825	7,038	71,022

Table 4 shows the growing stock in productive forestland in Denmark, Finland, Norway and Sweden. The Finnish data is from 2012 and is based on a four-year average. The Norwegian data is from 2010, where the last county-based forest inventory was carried out. The spruce and pine growing stocks in Denmark are aggregated to represent many different coniferous species. Spruce represents Norway spruce, Sitka Spruce, Nordmann fir and Noble fir, while pine represents Scots pine and other coniferous species. For Denmark, Norway and Sweden it is assumed that half of the total productive growing stock is pulpwood and the other half sawlogs as in Trømborg and Sjølie (2011).

Table 4. Growing stock for Denmark (Nord-Larsen, 2014), Finland (METLA, 2013), Sweden (Swedish Forest Agency, 2014) and Norway (Granhus, Hylen, & Ørnelund Nilsen, 2012).

	Spruce sawlogs	Pine Sawlogs	Non-coniferous sawlogs	Spruce pulpwood	Pine pulpwood	Non-coniferous pulpwood	TOTAL
			mill. [m^3 ub]				
D1	15.9	7.4	30.4	15.9	7.4	30.4	107.4
F1	12.8	33.2	0.3	43.4	158.5	38.6	286.8
F2	31.5	66.8	3.1	53	193	66.8	414.2
F3	5.5	4.5	0.6	10	15.3	8.8	44.7
F4	25.8	24.1	4.3	26.1	44.9	19.6	144.8
F5	29	17.3	4	29.7	33.4	26.4	139.8
F6	34.9	43.4	5.3	36.9	77	34.4	231.9
F7	21.4	21.5	3.1	23.7	40.7	18.7	129.1
F8	23.4	17.1	3.8	24.2	24.1	16.1	108.7
F9	25.2	25.3	5	25.1	34.2	24.2	139
F10	38.3	22.4	9	38.4	33.8	29	170.9
N1	7.4	5.9	0.6	7.4	5.9	0.6	27.8
N2	41.8	31.6	5.9	41.8	31.6	5.9	158.6
N3	26.1	7.2	4.4	26.1	7.2	4.4	75.4
N4	15.2	12.6	3.1	15.2	12.6	3.1	61.8
N5	15.7	11.7	6.4	15.7	11.7	6.4	67.6
N6	6.9	15	4.9	6.9	15	4.9	46.7
N7	3.2	6.2	3.7	3.2	6.2	3.7	26.2
N8	5.9	7.8	7.2	5.9	7.8	7.2	41.8
N9	26.8	9.7	3.8	26.8	9.7	3.8	80.6
N10	6	3.7	16.3	6	3.7	16.3	52
S1	30.1	76.1	22.6	30.1	76.1	22.6	257.6
S2	48.6	59.2	21.5	48.6	59.2	21.5	258.6
S3	63.9	49.4	18.7	63.9	49.4	18.7	264
S4	46.3	34.8	18.2	46.3	34.8	18.2	198.6
S5	63.3	100.6	24.4	63.3	100.6	24.4	376.6
S6	42.3	42.8	22.7	42.3	42.8	22.7	215.6
S7	64.2	46.4	19.5	64.2	46.4	19.5	260.2
S8	52.2	26.6	20.2	52.2	26.6	20.2	198
S9	69	60.3	28.5	69	60.3	28.5	315.6
S10	52.1	22.6	34.5	52.1	22.6	34.5	218.4
Total DK	15.9	7.4	30.4	15.9	7.4	30.4	107.4
Total FI	247.8	275.6	38.5	310.5	654.9	282.6	1809.9
Total NO	155	111.4	56.3	155	111.4	56.3	645.4
Total SW	532	518.8	230.8	532	518.8	230.8	2563.2

Table 5 shows the annual increment as a proportion of the growing stock in Denmark, Finland, Norway and Sweden. Danish increment values were given as coniferous, broadleaved and mixed species. Allocation to spruce and pine increment is assumed to be equal proportion of the growing stock, rendering these values the same, while non-coniferous and mixed species are aggregated into non-coniferous and is estimated as the proportion of the growing stock. For Denmark, Norway and Sweden, it is assumed that half of the total annual increment is pulpwood while the other half is sawlogs.

Table 5. Annual increment as % of growing stock under bark in Denmark (Nord-Larsen, 2014), Finland (METLA, 2013), Norway (Granhus et al., 2012) and Sweden (Swedish Forest Agency, 2014).

	Spruce sawlogs	Pine Sawlogs	Non-coniferous sawlogs	Spruce pulpwood	Pine pulpwood	Non-coniferous pulpwood
D1	11.92%	11.92%	4.80%	11.92%	11.92%	4.80%
F1	0.97%	3.52%	1.02%	0.97%	3.52%	1.02%
F2	2.04%	6.01%	1.93%	2.04%	6.01%	1.93%
F3	0.40%	0.53%	0.25%	0.40%	0.53%	0.25%
F4	1.33%	1.59%	0.68%	1.33%	1.59%	0.68%
F5	1.64%	1.19%	0.91%	1.64%	1.19%	0.91%
F6	1.91%	2.69%	1.12%	1.91%	2.69%	1.12%
F7	1.05%	1.28%	0.49%	1.05%	1.28%	0.49%
F8	1.14%	0.90%	0.47%	1.14%	0.90%	0.47%
F9	1.43%	1.36%	0.78%	1.43%	1.36%	0.78%
F10	1.93%	1.06%	0.78%	1.93%	1.06%	0.78%
N1	3.70%	3.30%	4.90%	3.70%	3.30%	4.90%
N2	4.30%	3.50%	4.20%	4.30%	3.50%	4.20%
N3	4.30%	3.60%	4.40%	4.30%	3.60%	4.40%
N4	3.70%	2.40%	4.00%	3.70%	2.40%	4.00%
N5	6.12%	3.10%	5.10%	6.12%	3.10%	5.10%
N6	4.40%	2.66%	4.03%	4.40%	2.66%	4.03%
N7	8.18%	3.23%	3.76%	8.18%	3.23%	3.76%
N8	6.31%	2.69%	3.32%	6.31%	2.69%	3.32%
N9	4.53%	2.42%	3.82%	4.53%	2.42%	3.82%
N10	3.72%	2.66%	3.89%	3.72%	2.66%	3.89%
S1	2.90%	3.21%	4.18%	2.90%	3.21%	4.18%
S2	3.27%	3.47%	4.14%	3.27%	3.47%	4.14%
S3	3.15%	3.75%	4.47%	3.15%	3.75%	4.47%
S4	3.53%	3.83%	5.08%	3.53%	3.83%	5.08%
S5	4.15%	3.91%	4.46%	4.15%	3.91%	4.46%
S6	4.43%	3.01%	3.92%	4.43%	3.01%	3.92%
S7	4.46%	3.75%	4.22%	4.46%	3.75%	4.22%
S8	4.41%	2.84%	3.38%	4.41%	2.84%	3.38%
S9	4.69%	3.23%	3.94%	4.69%	3.23%	3.94%
S10	5.18%	2.66%	3.50%	5.18%	2.66%	3.50%

4.2 ELASTICITIES OF ROUNDWOOD SUPPLY

The direct price elasticities of roundwood supply are based on econometric studies. 0.4 is used as the price elasticity for sawlogs in eastern and southern Norway (N1-N6), 0.3 at the west coast and northern Norway (N7-N8) and 0.4 is used for the rest (N9-N10). Pulpwood elasticities are set to 0.6, 0.4 and 0.5 in the same regions, respectively. The values are based on an exhaustive list of studies determining the price and volume elasticities (Trømborg & Sjølie, 2011). For Sweden, roundwood supply price elasticities are based on averages of findings in two studies (Ankarhem, 2005; Geijer, Bostedt, & Brannlund, 2011). The averages are set to 0.3 for sawlogs and 0.4 for pulpwood in all Swedish regions (Carlsson, 2012). Elasticities for Finland are set to 0.5 for sawlogs and 0.6 for pulpwood for all Finnish regions (Kuuluvainen et al., 1988). Danish roundwood are set to 0.4 for sawlogs and 0.6 for pulpwood.

4.3 PRICES

Table 6 shows the prices for roundwood assortments applied in the model. Norwegian and Finnish prices are given as roadside delivery prices while Swedish prices are mill gate delivery prices. Danish prices were made available through personal communication. To accommodate for the in-region transport costs for Norway, Finland and Denmark, additional transport costs are added based on estimated average regional transport distances and product category costs. Adjustments to the prices are made to calibrate the model to observed 2013 regional harvest volumes.

Table 6. Roadside roundwood prices in €/m³ for Denmark (Røge), Finland (METLA, 2013) and Norway (Statistics Norway, 2012) and delivery prices for Sweden (Swedish Forest Agency, 2014). When no price is given, data was not available. Prices for Non-coniferous sawlogs in Sweden are from Carlsson (2012). Exchange rates of 0.134, 0.128 and 0.116 (2013 exchange rates) are applied when converting Danish, Norwegian and Swedish currency to €.

	Spruce sawlogs	Spruce pulpwood	Pine sawlogs	Pine pulpwood	Non-coniferous sawlogs	Non-coniferous pulpwood
D1	48	33	47	31	109	44
F1	54	34	56	33	1000	35
F2	55	31	61	29	1000	31
F3	52	31	56	31	106	38
F4	55	29	56	30	100	39
F5	55	34	57	32	96	37
F6	56	29	58	35	97	46
F7	54	32	56	33	101	44
F8	59	32	59	33	106	34
F9	53	27	55	29	98	33
F10	56	37	59	30	99	34
N1	49	33	49	31	117	39
N2	50	30	50	28	105	35
N3	56	31	52	28	107	41
N4	52	31	48	30	109	37
N5	46	29	44	22	108	37
N6	44	28	46	22	125	31
N7	48	28	49	29	110	36
N8	42	26	42	22	107	22
N9	45	28	58	26	106	30
N10	44	34	43	28	108	34
S1	51	34	62	34	118	37
S2	51	31	58	32	118	37
S3	50	37	55	33	118	35
S4	51	32	61	33	118	44
S5	55	28	60	29	124	36
S6	58	33	62	33	118	35
S7	56	32	52	31	118	41
S8	55	36	53	34	118	38
S9	59	29	58	30	135	42
S10	63	36	65	34	130	44

4.4 HARVEST RESIDUES

Table 7 displays the parameters used to model the harvest residue supply (which can be viewed as a marginal cost curve). The total available harvest residue quantity is assumed to be 30% of the roundwood harvest for Finland and Sweden, which both utilize root harvesting (Ankarhem, 2005; Athanassiadis, Lundström, & Nordfjell, 2011), and 10% for Denmark and Norway which only exploit branch and top components (Skovsgaard & Nord-Larsen, 2011; Trømborg & Sjølie, 2011). Supply of harvest residues in the reference year is determined differently for each country. It is assumed that no harvest residues were collected in 2013 in Norway. The Swedish supply quantity is based on average regional collection between 2011-2013 (Swedish Forest Agency, 2014) . The supply level for Denmark is set to 75% of the potential based on existing studies (Kuiperm & Oldenburger, 2006). Since no recent studies determining regional harvest residue supply were found for Finland, the level of supply of harvest residues is based on harvest residue consumption in the Finnish energy sector (Koponen et al., 2015). Regional consumption of harvest residues in Finland is estimated based on the national consumption value distributed at regional level, assuming equal consumption per inhabitant. The slopes employed for the Norwegian and Swedish harvest residue supply functions are both based on available data from existing models (Carlsson, 2012; Trømborg & Sjølie, 2011). Since the regionalization for this model is different from regionalization applied in the source studies, the slopes employed in this model are based on weighted averages. These are estimated using the original slopes weighted by the supply potentials. The slopes for the Finnish harvest residue supply functions are estimated as the average of the Swedish slopes used in this study, because no studies determining this were found for Finland. Finally, the intercepts are based on economic-engineering approaches used to quantify the costs of collecting the harvest residues and delivering them to the market (Carlsson, 2012; Rørstad et al., 2010; Routa et al., 2013; Trømborg & Sjølie, 2011).

Table 7. Harvest residue supply function parameters. Heating value used is 0.82 MWh/m³ (Athanassiadis et al., 2011).

	Intercept	Slope	Supply	Supply potential
	[€/MWh]		[1000 GWh]	[1000 GWh]
D1	20	0.003311	167	223
F1	20	0.003311	144	70,529
F2	20	0.003311	435	101,915
F3	20	0.003311	978	10,999
F4	20	0.003311	801	35,652
F5	20	0.003311	621	34,376
F6	20	0.003311	1089	57,022
F7	20	0.003311	663	31,783
F8	20	0.003311	717	26,723
F9	20	0.003311	459	34,188
F10	20	0.003311	717	42,071
N1	21	0.004831	0	1,800
N2	21	0.005275	0	2,100
N3	21	0.001512	0	7,250
N4	21	0.004283	0	3,000
N5	21	0.003979	0	4,700
N6	21	0.009192	0	2,550
N7	21	0.026919	0	750
N8	21	0.052341	0	530
N9	21	0.021283	0	1,250
N10	21	0.014085	0	1,800
S1	16	0.005501	328	63,363
S2	16	0.006286	460	63,624
S3	16	0.003607	229	64,933
S4	16	0.003607	379	48,843
S5	16	0.003607	711	92,694
S6	16	0.002	1,292	53,033
S7	16	0.002	712	64,019
S8	16	0.002	915	48,712
S9	16	0.00225	1,813	77,626
S10	16	0.00225	1721	53,732

5 FOREST INDUSTRIAL PRODUCTION

5.1 SAWNWOOD

In order to determine sawnwood production quantity in Norway, the regional sold quantity of the included species categories of sawlogs is assumed to be representative of the regional sawnwood production. For each region, the assumed roundwood quantity used for sawnwood production is estimated by adding the regional sold quantity of sawlogs with a proportion of the net import. The proportion of the net import is assumed to follow the regional proportional sold quantity. It is assumed that the saw log to sawnwood ratio is 1:0,531 (see Table 9), which is the average for members of the Norwegian Sawmilling Industry in 2010 (Larnøy, 2011). The trade balance quantity is estimated by subtracting the export from import. 50% is assumed to be sawlogs for both spruce and pine. Labour and energy inputs in production are based on data found in Trømborg and Sjølie (2011). Regional sawnwood production quantity for Sweden and Finland is determined using a combination of the sawmill database (Nylinder, 2015) and company websites. To locate the sawmills and estimate the production sawmill production volumes, the sawmill database was used. Subsequent to registering production volume and region of each sawmill, company website access was attempted to determine whether listed production volumes corresponded with estimates from the sawmill database. In almost all cases, the quantities and species listed on the sawmill database matched the company website data, when company website data was available. In cases where there was a mismatch, the company website data is used. In cases where there was no company website data, the data provided by the sawmill database is applied. The production quantities in the sawmill database were given as either softwood, whitewood or redwood. It is assumed redwood and whitewood are pine and spruce, respectively. When the production quantities were given as softwood the regional species-specific inputs in production levels are used to determine whether spruce or pine was used in production (see Table 9). No distinction was made between conifers, so coniferous sawnwood production is assumed to follow the coniferous harvest proportions. As a final step to ensure that the estimated production values correspond to national production values for Finland, Norway and Sweden, the estimated production values were compared to national production figures (FAO, 2013). For Finland and Sweden, the estimated production quantity was within 95% of the observed national production in 2013, but for Norway the estimated production was significantly lower than the observed national production figures. This is presumably because production in small sawmills were not accounted for. To accommodate this, the production discrepancy is allocated proportionately according to species and regional production. The sawnwood production values for Denmark are based on national production data (FAOSTAT, 2000-2014), since Denmark is only represented by one region. Energy inputs are based on the same source used for the Norwegian data (Trømborg & Sjølie, 2011). Labour inputs are estimated using linear regressions since this data was only available for a limited number of sawmills. Initially, the sawmills are categorized as either small (< 100,000 m^3 sawnwood), medium (100,000-199,999 m^3 sawnwood) or large (>=200,000 m^3 sawnwood) depending on annual production. For each type of sawmill labour input quantity per m^3 produced sawnwood is estimated using linear regressions for Finland, Norway and Sweden (see Table 9). Due lack of mill-specific production data for Denmark, Swedish labour and energy input data is applied. In addition, it is assumed that all Danish sawmills operate at a small (<100,000 m^3 sawnwood) capacity.

Table 8. Sawnwood production given in 1000 m^3. S, M and L represent small, medium and large sawmills, respectively.

	Spruce sawnwood			Pine Sawnwood			Non-coniferous sawnwood		
	S	M	L	S	M	L	S	M	L
D1	198	0	0	92	0	0	67	0	0
F1	0	0	400	0	100	0	0	0	0
F2	0	63	282	0	357	898	0	0	0
F3	0	0	200	60	0	0	0	0	0
F4	0	50	104	0	50	156	0	0	0
F5	0	100	260	0	0	0	0	0	0
F6	0	0	1,190	0	0	1345	0	0	0
F7	0	260	530	0	50	460	0	0	0
F8	85	0	1,000	0	0	780	0	0	0
F9	0	0	200	0	0	250	0	0	0
F10	0	0	0	0	0	0	0	0	0
N1	0	0	0	0	0	0	1	0	0
N2	82	27	0	0	27	0	0	0	0
N3	71	61	120	100	0	106	0	0	0
N4	45	154	106	0	0	0	0	0	0
N5	71	0	0	51	0	0	2	0	0
N6	0	0	66	21	0	66	0	0	0
N7	8	0	0	8	0	0	0	0	0
N8	19	0	0	0	0	0	1	0	0
N9	17	0	0	17	0	0	0	0	0
N10	0	156	0	0	0	0	0	0	0
S1	16	0	0	249	100	440	0	0	0
S2	286	0	470	125	546	0	0	0	0
S3	176	0	300	119	0	0	0	0	0
S4	55	260	450	95	120	460	0	0	0
S5	484	110	320	277	540	1,235	0	0	0
S6	150	0	990	50	295	439	0	0	0
S7	258	130	680	0	0	290	0	0	0
S8	192	0	250	40	0	0	0	0	0
S9	651	1,594	710	276	404	220	0	0	0
S10	376	1,077	220	40	0	650	0	0	0

Table 9. Input and output values for production of sawnwood. S, M and L represent small, medium and large sawmills. Positive values are inputs while negative values are surplus outputs. Each unit of 1.88 m³ sawlogs produces exactly 1 m³ sawnwood. All inputs and outputs are in m³ except labour and energy, which are given in hours and MWh, respectively. A distinction between spruce, pine and non-coniferous sawnwood is made in the model, but is not displayed here.

	Mill size	Input and outputs						
		Sawlogs	Chips	Dust	Bark	Shavings	Labour	Energy
Denmark	S	1.88	-0.56	-0.15	-0.17	-0.035	0.46	0.12
Finland	S	1.88	-0.56	-0.15	-0.17	-0.035	1.08	0.12
	M	1.88	-0.56	-0.15	-0.17	-0.035	0.57	0.12
	L	1.88	-0.56	-0.15	-0.17	-0.035	0.4	0.12
Norway	S	1.88	-0.56	-0.15	-0.17	-0.035	0.72	0.12
	M	1.88	-0.56	-0.15	-0.17	-0.035	0.42	0.12
	L	1.88	-0.56	-0.15	-0.17	-0.035	0.46	0.12
Sweden	S	1.88	-0.56	-0.15	-0.17	-0.035	0.66	0.12
	M	1.88	-0.56	-0.15	-0.17	-0.035	0.42	0.12
	L	1.88	-0.56	-0.15	-0.17	-0.035	0.31	0.12

5.2 BOARDS

The Finnish board producers were identified through company websites. In total, there were 10 producers of boards and 8 of these listed their respective production capacity. The accumulated capacity for the remaining two producers is estimated by subtracting the total production volume of the other producers from the national production level. It is assumed that the two remaining mills produced 50% each of the identified deficit. 5 of the mills stipulated the pulpwood species, and for the remaining mills, it is assumed spruce pulpwood is used in production. Labour inputs for production of plywood, particle boards and fibreboards are determined using a logarithmic regression based on Finnish labour data collected from the company websites. The input/output relations for production are based on Swedish and Norwegian averages and energy inputs are based on data collected from interviews with Norwegian producers (Trømborg & Sjølie, 2011). The Swedish board producers were identified through the Swedish Forest Industries Federation (SFIF). The input and output relation were then identified through company websites except for energy inputs which are based on interviews with Norwegian producers (Trømborg & Sjølie, 2011). The data for the Norwegian producers is identical to data found in the NTM3 report (Trømborg & Sjølie, 2011). The production values for the Danish producers for particle boards and fibreboards are based on national reporting values (FAO, 2013). Input/output relations for production of particleboards and fibreboards in Denmark were not available, so averages of the Norwegian technologies are applied. The input/output relations and production volume can be found in Table 10 and in Table 11, respectively.

Table 10. Input/output relations for board production. For each board producer a technology is specified (e.g. FPly7 for the 7th plywood producer identified in Finland). Positive values are inputs while negative values are surplus outputs and one unit (m^3 or tonne) is produced for the quantity of input listed for each technology. All inputs and outputs are in m^3 except labour and energy, which are given in hours and MWh, respectively.

		Sawlogs		Pulpwood			Dust	Bark	Shav	Chips	Labour	Energy
		S	NC	S	P	NC						
Denmark	DPart1	0	0	0.33	0	0.01	0.56	-0.04	0.23	0	1.4	0.77
	DFibr1	0	0	0.34	0.89	0.08	1.32	0	0	0	4.9	0.52
Finland	FPly1	2.21	0	0	0	0	0	0	0	0	2.03	1
	FPly2	2.21	0	0	0	0	0	0	0	0	2.03	1
	FPly3	0	2.21	0	0	0	0	0	0	0	1.67	1
	FPly4	0	2.21	0	0	0	0	0	0	0	2.32	1
	FPly5	0	2.21	0	0	0	0	0	0	0	2.35	1
	FPly6	2.21	0	0	0	0	0	0	0	0	2.14	1
	FPly7	0	2.21	0	0	0	0	0	0	0	2.21	1
	FPly8	2.21	0	0	0	0	0	0	0	0	1.27	1
	FPart1	0	0	0.51	0	0	0.42	-0.03	0.3	0	2.35	1
	FFiber1	0	0	0.87	0	0	0.88	0	0	0	2.03	1
Norway	NPart1	0	0	0.19	0	0	0.96	-0.01	0.45	0	0.4	0.15
	NPart2	0	0	0.46	0	0.02	0.16	-0.07	0	0	2.4	1.38
	NFiber1	0	0	0.52	0	0	1.92	0	0	0	2.37	0.52
	NFiber2	0	0	0.16	1.78	0.16	0.72	0	0	0	7.42	2.69
Sweden	SPart1	0	0	0.27	0	0.3	0.6	0	0	0	0.18	1
	SPart2	0	0	0.48	0	0.06	0.43	0	0	0.06	1.81	1
	SPart3	0	0	0.47	0	0.47	0.02	0	0	0.02	0.46	1
	SPly1	0	0	1.86	0	0	0	0	0	0	1.86	1

Table 11. Production of boards. For each board producer a technology is specified (e.g. FPly7 for the 7th plywood producer identified in Finland). Fibreboard units are in tonnes, while m³ is used for particle board and plywood.

Denmark	Region	D1									
	DPart1	346,000									
	DFibr1	5,080									
Finland	Region	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10
	FPly1	0	0	0	0	0	0	0	0	65,000	0
	FPly2	0	0	0	65,000	0	0	0	0	0	0
	FPly3	0	0	0	0	0	55,000	0	0	0	0
	FPly4	0	0	0	120,000	0	0	0	0	0	0
	FPly5	0	0	0	0	0	0	0	0	100,000	0
	FPly6	0	0	0	0	0	0	0	70,000	0	0
	FPly7	0	0	0	0	0	0	0	75,000	0	0
	FPly8	0	0	0	0	0	0	0	0	480,000	0
	FPart1	0	0	0	0	0	0	0	100,000	0	0
	FFiber1	0	0	0	0	0	0	0	65,000	0	0
Sweden	Region	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10
	SPart1	0	0	0	0	0	0	0	0	700,000	0
	SPart2	0	0	54,000	0	0	0	0	0	0	0
	SPart3	0	0	0	0	0	0	43,000	0	0	0
	SPly1	0	0	0	0	0	0	0	90,000	0	0
Norway	Region	N1	N2	N3	N4	N5	N6	N7	N8	N9	N10
	NPart1	0	0	360,000	0	0	0	0	0	0	0
	NPart2	0	0	0	0	0	0	0	0	0	55,000
	NFiber1	0	0	0	54,000	0	0	0	0	0	0
	NFiber2	0	0	0	0	0	0	55,000	0	0	0

5.3 PULP AND PAPER

For all the pulp and paper producers, a technology separation is conducted to separate production lines into the various grades of pulp and paper, when production of paper was observed to be integrated with pulp production. Hence, separate technologies are specified for integrated mills producing both pulp and paper. This alleviates balancing and calibration of pulpwood use in production, pulp input in production and trade of pulpwood and pulp.

5.3.1 NORWAY

The data for the Norwegian pulp mills is derived from NTMIII, which had its reference year in 2010 (Trømborg & Sjølie, 2011) and updated based on existing 2014 production values (NPPA, 2014). It is assumed that no changes in input-output relations occurred between 2010 and 2014. See Table 12 and Table 13 for input and output relations and production capacity, respectively. Recycled paper is used as input in one paper mill and input is displayed in Table 12.

Table 12 Input coefficients for production of one tonne pulp or paper in Norway. Positive values are inputs. SPECP = Sulphite and dissolving pulp, CHEM = Sulphate pulp, CTMP = Chemi-thermomechanical pulp, MECH = Mechanical pulp, NEWS = Newsprint, OPBO = other paper and board, PRWR = Printing and writing paper. Wood inputs are in m^3, pulp and recycled paper in tonnes, while labour and energy are given in hours and MWh, respectively.

	Spruce pulpwood	Pine pulpwood	CHEM	Recycled paper	Bark	Labour	Energy
SPECP1	6.25	0	0	0	-0.68	3.49	1.63
CTMP1	2.68	0	0	0	-0.29	1.11	1.64
MECH1	2.08	0.52	0	0	-0.27	1.02	1.56
MECH2	2.4	0	0	0	-0.26	1.11	1.14
NEWS1	1.89	0	0.05	0	-0.2	1.62	2.37
OPBO1	0	1	0	0	0	3.45	2.71
OPBO2	0	0	0.92	0.1	0	7.63	2
OPBO3	0	0	1.02	0	0	4.59	4.67
OPBO4	0	0	0.92	0	0	6.96	3.82
PRWR1	1.75	0	0.17	0	-0.18	2.65	2.02
PRWR2	1.3	0	0.11	0	-0.16	1.82	2.59

Table 13. Production capacity in tonnes for technologies in pulp and paper mills in Norway. SPECP = Sulphite and dissolving pulp, CHEM = Sulphate pulp, CTMP = Chemi-thermomechanical pulp, MECH = Mechanical pulp, NEWS = Newsprint, OPBO = other paper and board, PRWR = Printing and writing paper.

	N1	N2	N3	N4	N5	N6	N7	N8	N9	N10
SPECP1	160,000	0	0	0	0	0	0	0	0	0
CTMP1	0	0	0	0	0	0	0	0	0	130,000
MECH1	0	0	0	0	0	42,000	0	0	0	0
MECH2	0	0	0	0	0	70,000	0	0	0	0
NEWS1	0	0	0	0	0	0	0	0	0	470,000
OPBO1	40,000	0	0	0	0	0	0	0	0	0
OPBO2	0	0	0	0	15,000	0	0	0	0	0
OPBO3	30,000	0	0	0	0	0	0	0	0	0
OPBO4	0	0	0	0	22,000	0	0	0	0	0
PRWR1	550,000	0	0	0	0	0	0	0	0	0
PRWR2	0	0	0	0	50,000	0	0	0	0	0

5.3.2 SWEDEN

The energy inputs (purchased electricity) and product specific production capacities for the Swedish pulp and paper mills is derived from the Swedish forest industries federation's environmental database (Swedish Forest Industries Federation, 2013). Purchased energy is given for each production unit, but some production units produced several types of pulp and paper grades. To determine purchased energy inputs for each production line in each production unit, linear regression analysis was performed using production units with only one grade to determine energy inputs per unit output for production units with several grades. Using this method, energy inputs for each technology in each production facility is determined (see Table 14). Own produced energy was ignored, if this was not sold at the market. The number of employees for each production facility was determined by visiting company websites. A large proportion listed this figure, but in most cases it was an aggregate number representing production of several grades. To accommodate this, a similar approach is applied using linear regression to determine number of workers needed for each grade in each facility (see Table 14). In order to determine the pulpwood input for each pulping technology in each mill, regional species-specific pulpwood use in pulp production (Lundberg, 2014) and Norwegian product-specific pulpwood input per unit pulp output is used. The Norwegian pulpwood to pulp input and output relations multiplied by Swedish regional pulp production fitted well with regional pulpwood input used in production of pulp and was within 95% of the actual Swedish regional pulpwood use in production of pulp. This indicates that the production lines for production of pulp in Norway and Sweden use roughly the same amount of pulpwood per unit produced for each pulp product aggregate. The regional pulpwood input was provided as either spruce, pine, non-coniferous or chips. These species and assortment proportions are assumed to represent the proportions used in production (see Table 14). Pulp input for production of paper for each paper technology is determined by using average input pulp values for production of papers grades. This was derived from Swedish integrated mill data with only one pulp category aggregate is used to produce one paper product (Swedish Forest Industries Federation, 2013). It is assumed that this relational value is representative for all pulp-to-paper conversions, but this is not the case. The estimated averages underestimated the use of pulp (surplus pulp production) for production of paper, so the average used of pulp in production of other paper and paperboard, newsprint and linerboard is increased to ensure full utilization of produced pulp, taking into account the regional and national trade of pulp (see Table 14 for pulp inputs in production of paper). The production capacities are presented in Table 15. Inputs relations for each technology using recycled paper is included (Swedish Forest Industries Federation, 2013).

Table 14. Input coefficients for production of one tonne pulp or paper in Sweden. Positive values are inputs. SP = Spruce pulpwood, PP = Pine pulpwood, NCP = non-coniferous pulpwood, RCYC = recycled paper, SPECP = Sulphite and dissolving pulp, CHEM = Sulphate pulp, CTMP = Chemi-thermomechanical pulp, LINR = Liner/Case materials, MECH = Mechanical pulp, NEWS = Newsprint, OPBO = other paper and board, PRWR = Printing and writing paper.

	SP	PP	NCP	Chips	CHEM	SPEC	CTMP	MECH	RCYC	Labour	Energy
SPECP1	2.31	1.85	1.06	1.04	0	0	0	0	0	0.27	1.18
SPECP2	2.46	1.13	0.93	1.73	0	0	0	0	0	0.82	0.55
CHEM1	1.68	1.35	0.77	0.75	0	0	0	0	0	0.85	0.15
CHEM2	1.68	1.35	0.77	0.75	0	0	0	0	0	0.75	0.35
CHEM3	1.38	1.59	0.70	0.86	0	0	0	0	0	0.82	0.02
CHEM4	1.35	1.43	0.73	1.03	0	0	0	0	0	0.60	0.44
CHEM5	1.79	0.82	0.67	1.26	0	0	0	0	0	0.81	0.39
CHEM6	1.35	1.43	0.73	1.03	0	0	0	0	0	1.35	0.11
CHEM7	1.38	1.59	0.70	0.86	0	0	0	0	0	0.60	0.44
CHEM8	1.38	1.59	0.70	0.86	0	0	0	0	0	0.84	0.21
CHEM9	1.68	1.35	0.77	0.75	0	0	0	0	0	0.82	0.27
CHEM10	1.68	1.35	0.77	0.75	0	0	0	0	0	0.15	0.85
CHEM11	1.68	1.35	0.77	0.75	0	0	0	0	0	0.84	0.17
CHEM12	1.35	1.43	0.73	1.03	0	0	0	0	0	0.84	0.25
CHEM13	1.38	1.59	0.70	0.86	0	0	0	0	0	0.85	0.36
CHEM14	1.38	1.59	0.70	0.86	0	0	0	0	0	0.85	0.51
CHEM15	1.38	1.59	0.70	0.86	0	0	0	0	0	0.74	0
CHEM16	1.38	1.59	0.70	0.86	0	0	0	0	0	0.66	0.34
CHEM17	1.68	1.35	0.77	0.75	0	0	0	0	0	0.81	0.55
CHEM18	1.79	0.82	0.67	1.26	0	0	0	0	0	0.56	0
CHEM19	1.79	0.82	0.67	1.26	0	0	0	0	0	0.77	0
CHEM20	1.79	0.82	0.67	1.26	0	0	0	0	0	0.74	0
CTMP1	0.99	0.79	0.45	0.44	0	0	0	0	0	0.24	0.93
CTMP2	0.82	0.94	0.41	0.51	0	0	0	0	0	0.31	0
CTMP3	0.80	0.85	0.43	0.61	0	0	0	0	0	0.32	0.97
CTMP4	0.99	0.79	0.45	0.44	0	0	0	0	0	0.29	0.88
CTMP5	1.05	0.49	0.40	0.74	0	0	0	0	0	0.33	1.26
LINR1	0.40	0	0	0	0	0	0.61	0	0	0.85	0.43
LINR2	0.40	0	0	0	0.67	0	0	0	0	0.83	0.11
LINR3	0.40	0	0	0	0.67	0	0	0	0	0.43	0.21
LINR4	0	0	0	0	0.58	0	0	0	0.47	0.35	0.21
LINR5	0	0	0	0	0.80	0	0	0	0.20	0.23	0.12
MECH1	0.99	0.79	0.45	0.44	0	0	0	0	0	0.30	0.56
MECH2	1.05	0.49	0.40	0.74	0	0	0	0	0	0.14	0.42
MECH3	0.98	0.45	0.37	0.69	0	0	0	0.00	0	0.72	2.70
MECH4	0.74	0.79	0.40	0.57	0	0	0	0	0	0.36	2.68
MECH5	0.92	0.74	0.42	0.41	0	0	0	0	0	2.42	2.62
MECH6	0.76	0.88	0.39	0.47	0	0	0	0	0	0.33	2.63
MECH7	0.98	0.45	0.37	0.69	0	0	0	0	0	0.68	2.48
MECH8	0.74	0.79	0.40	0.57	0	0	0	0	0	0.38	2.62
News1	0.4	0	0	0	0	0	0	0.70	0	0.48	2.14
News2	0	0	0	0	0	0	0	0.80	0.27	0.23	0.47
News3	0.4	0	0	0	0	0	0	0.70	0	0.26	0.55
News4	0	0	0	0	0	0	0	0.47	0.49	0.18	0.51
News5	0.4	0	0	0	0	0	0	0.70	0	0.30	1.18
OPBO1	0	0	0	0	0.98	0	0	0	0	7.44	3.17
OPBO2	0	0	0	0	0.62	0	0	0	0	1.03	0.52
OPBO3	0	0	0	0	0.72	0	0	0	0	0.98	0.41
OPBO4	0	0	0	0	0.35	0	0	0	0	1.18	0.22
OPBO5	0	0	0	0	0.98	0	0	0	0	0.75	0.51
OPBO6	0	0	0	0	0.93	0	0	0	0.07	1.17	0.28

OPBO7	0	0	0	0	0	0	0	0	1.10	1.94	0.82
OPBO8	0	0	0	0	0.78	0	0	0	0	1.05	0.30
OPBO9	0	0	0	0	0	0	0	0	0.86	3.45	1.35
OPBO10	0	0	0	0	0.98	0	0	0	0	6.12	0.94
OPBO11	0	0	0	0	0.98	0	0	0	0	6.33	1.16
OPBO12	0	0	0	0	1.04	0	0	0	0	1.43	0.52
OPBO13	0	0	0	0	0.98	0	0	0	0	7.44	1.41
OPBO14	0	0	0	0	1	0	0	0	0	4.47	0.88
OPBO15	0	0	0	0	1.07	0	0	0	0	2.29	0.41
OPBO16	0	0	0	0	0	1.32	0	0	0	5.92	1.15
OPBO17	0	0	0	0	0.98	0	0	0	0	5.16	1.26
OPBO18	0	0	0	0	0.98	0	0	0	0	6.63	1.54
OPBO19	0	0	0	0	0.98	0	0	0	0	3.55	0.97
OPBO20	0	0	0	0	0	0	0	0	0.73	7.31	1.29
OPBO21	0	0	0	0	0	0	0	0	0.81	2.84	1.61
OPBO22	0	0	0	0	0	0	0.49	0	0	1.10	0.77
OPBO23	0	0	0	0	0.43	0	0.33	0	0	0.62	0.63
OPBO24	0	0	0	0	0.98	0	0	0	0	6.50	1.37
OPBO25	0	0	0	0	0.98	0	0	0	0	6.63	1.20
OPBO26	0	0	0	0	0.98	0	0	0	0	4.17	2.29
PRWR1	0	0	0	0	0.27	0.17	0	0.32	0	1.49	0.53
PRWR2	0	0	0	0	0	0	0	0.75	0	1.61	0.62
PRWR3	0	0	0	0	0	0	0	0.89	0	0.68	0.49
PRWR4	0	0	0	0	0.27	0.17	0	0.32	0	4.73	0.92
PRWR5	0	0	0	0	0.45	0	0	0	0	0.62	0.28
PRWR6	0	0	0	0	0	0	0	0.75	0	0.80	0.49
PRWR7	0	0	0	0	0	0	0	0.75	0	0.92	0.51
PRWR8	0	0	0	0	0	0.72	0	0	0	0.94	0.29

Table 15. Production capacity in tonne for technologies in pulp and paper mills in Sweden. SPECP = Sulphite and dissolving pulp, CHEM = Sulphate pulp, CTMP = Chemi-thermomechanical pulp, LINR = Liner/Case materials, MECH = Mechanical pulp, NEWS = Newsprint, OPBO = other paper and board, PRWR = Printing and writing paper. There is no production in region S3.

	S1	S2	S4	S5	S6	S7	S8	S9	S10
SPECP1	0	0	0	0	0	37,000	0	0	0
SPECP2	0	0	0	0	0	0	0	0	301,000
CHEM1	0	0	0	0	0	243,000	0	0	0
CHEM2	0	0	0	0	0	409,000	0	0	0
CHEM3	304,000	0	0	0	0	0	0	0	0
CHEM4	0	0	0	659,000	0	0	0	0	0
CHEM5	0	0	0	0	0	0	0	289,000	0
CHEM6	0	0	0	347,000	0	0	0	0	0
CHEM7	0	0	666,000	0	0	0	0	0	0
CHEM8	0	0	263,000	0	0	0	0	0	0
CHEM9	0	0	0	0	0	180,000	0	0	0
CHEM10	0	0	0	0	0	0	65,000	0	0
CHEM11	0	0	0	0	0	205,000	0	0	0
CHEM12	0	0	0	208,000	0	0	0	0	0
CHEM13	216,,000	0	0	0	0	0	0	0	0
CHEM14	0	240,000	0	0	0	0	0	0	0
CHEM15	0	0	417,000	0	0	0	0	0	0
CHEM16	549,000	0	0	0	0	0	0	0	0
CHEM17	0	0	0	0	0	317,000	0	0	0
CHEM18	0	0	0	0	0	0	0	750,000	0
CHEM19	0	0	0	0	0	0	0	0	274,000
CHEM20	0	0	0	0	0	0	0	0	422,000
CTMP1	0	0	0	0	0	72,000	0	0	0
CTMP2	0	0	94,000	0	0	0	0	0	0
CTMP3	0	0	0	175,000	0	0	0	0	0
CTMP4	0	0	0	0	0	246,000	0	0	0
CTMP5	0	0	0	0	0	0	0	130,000	0
LINR1	0	0	0	0	0	140,000	0	0	0
LINR2	0	0	0	129,000	0	0	0	0	0
LINR3	324,000	0	0	0	0	0	0	0	0
LINR4	0	417,000	0	0	0	0	0	0	0
LINR5	682,000	0	0	0	0	0	0	0	0
MECH1	0	0	0	0	0	229,000	0	0	0
MECH2	0	0	0	0	0	0	0	53,000	0
MECH3	0	0	0	0	0	0	0	488,000	0
MECH4	0	0	0	0	542,000	0	0	0	0
MECH5	0	0	0	0	0	53,000	0	0	0
MECH5	0	0	606,000	0	0	0	0	0	0
MECH6	0	0	0	0	0	0	0	0	257,000
MECH7	0	0	0	512,000	0	0	0	0	0
News1	0	0	0	0	0	0	148,000	0	0
News2	0	0	0	0	0	0	0	404,000	0
News3	0	0	339,000	0	0	0	0	0	0
News4	0	0	0	0	0	0	0	0	543,000
News5	0	0	0	287,000	0	0	0	0	0
OPBO1	0	0	0	0	0	13,000	0	0	0
OPBO2	0	0	0	0	0	392,000	0	0	0
OPBO3	0	0	0	0	0	420,000	0	0	0
OPBO4	330,000	0	0	0	0	0	0	0	0
OPBO5	0	0	0	589,000	0	0	0	0	0
OPBO6	0	0	0	0	0	0	0	295,000	0

OPBO7	0	0	0	0	0	0	0	169,000	0
OPBO8	0	0	0	381,000	0	0	0	0	0
OPBO9	0	0	0	0	0	0	73,000	0	0
OPBO10	0	0	0	0	0	0	26,000	0	0
OPBO11	0	0	0	0	0	0	24,000	0	0
OPBO12	0	0	254,000	0	0	0	0	0	0
OPBO13	0	0	0	0	0	0	0	13,000	0
OPBO14	0	0	0	0	0	0	48,000	0	0
OPBO15	0	0	0	0	0	134,000	0	0	0
OPBO16	0	0	0	0	0	28,000	0	0	0
OPBO17	0	0	0	0	0	37,000	0	0	0
OPBO18	0	0	0	0	0	0	8,000	0	0
OPBO19	0	0	0	0	0	0	0	70,000	0
OPBO20	0	0	0	0	0	0	0	15,000	0
OPBO21	0	0	0	0	0	0	98,000	0	0
OPBO22	0	0	0	358,000	0	0	0	0	0
OPBO23	0	0	0	0	0	739,000	0	0	0
OPBO24	0	0	0	0	0	23,000	0	0	0
OPBO25	0	0	0	0	0	0	0	54,000	0
OPBO26	0	0	0	0	0	0	0	0	8,000
PRWR1	0	0	0	238,000	0	0	0	0	0
PRWR2	0	0	0	0	0	0	0	217,000	0
PRWR3	0	0	0	0	611,000	0	0	0	0
PRWR4	0	0	0	0	0	0	0	0	90,000
PRWR5	0	0	689,000	0	0	0	0	0	0
PRWR6	0	0	508,000	0	0	0	0	0	0
PRWR7	0	0	0	430,000	0	0	0	0	0
PRWR8	0	0	0	0	0	0	0	0	419,000

5.3.3 FINLAND

The Finnish pulp and paper production facilities were identified though company websites. For each production unit identified, one technology per pulp or paper product produced is included in the model. As none of the companies provided data on energy inputs in production, it is assumed energy input is the same as in Sweden for the various pulp and paper grades. Consequently, linear regressions based on Swedish energy input data are employed to determine energy input in production for the Finnish pulp and paper technologies. Number of workers was identified through company websites, but data availability was limited. Not all companies listed number of workers and most did not list number of workers per production line. To determine the number of workers for each production line for each mill, when this was not provided by the companies, linear regressions based on available Finnish data and distinguishing only between pulp and paper are used. Pulpwood input in production of pulp is estimated in the same way as for the Swedish pulp technologies; the pulpwood-to-pulp relations for the Norwegian technologies are applied. In order to determine the pulpwood input for each technology in each pulping mill, regional species specific pulpwood use in pulp production (METLA, 2013) and Norwegian grade specific pulpwood input per unit pulp output is used. The Norwegian pulpwood to pulp input and output relations multiplied by regional pulp production fitted well with regional pulpwood input used in production of pulp and was within 86% of the actual Finnish regional pulpwood use in production of pulp. The input output relation for pulp to paper grades are based on Swedish regressions. Slight modifications in values are made to ensure full utilization of pulp (produced – exported from region + imported to region). See Table 16 for the input and output relations and Table 17 for regional capacities. The quantity of recycled paper was identified based on (FAO, 2013) and assumed evenly used in production of newsprint, linerboard and other paper and paperboard (see Table 16).

Table 16. Input coefficients for production of one tonne pulp or paper in Finland. Positive values are inputs. SP = Spruce pulpwood, PP = Pine pulpwood, NCP = non-coniferous pulpwood, RCYC = recycled paper, CHEM = Sulphate pulp, CTMP = Chemi-thermomechanical pulp, LINR = Liner/Case materials, MECH = Mechanical pulp, NEWS = Newsprint, OPBO = other paper and board, PRWR = Printing and writing paper.

	SP	PP	NCP	Chips	CHEM	CTMP	MECH	RCYC	Labour	Energy
CHEM1	0.45	2.22	1.49	0.2	0	0	0	0	0.19	0.25
CHEM2	0.45	2.22	1.49	0.2	0	0	0	0	0.18	0.25
CHEM3	0.45	2.22	1.49	0.2	0	0	0	0	0.32	0.25
CHEM4	0.45	2.22	1.49	0.2	0	0	0	0	0.43	0.25
CHEM5	0	4.54	0	0	0	0	0	0	0.77	0.25
CHEM6	0.45	2.22	1.49	0.2	0	0	0	0	0.77	0.25
CHEM7	0.45	2.22	1.49	0.2	0	0	0	0	0.23	0.25
CHEM8	0.45	2.22	1.49	0.2	0	0	0	0	0.33	0.25
CHEM9	0.45	2.22	1.49	0.2	0	0	0	0	0.38	0.25
CTMP1	2.68	0	0	0	0	0	0	0	0.17	1.01
CTMP2	2.68	0	0	0	0	0	0	0	0.77	1.01
CTMP3	2.68	0	0	0	0	0	0	0	0.27	1.01
MECH1	2.08	0	0.34	0	0	0	0	0	0.29	2.1
MECH2	2.08	0	0.34	0	0	0	0	0	0.56	2.1
MECH3	2.08	0	0.34	0	0	0	0	0	0.77	2.1
MECH4	2.08	0	0.34	0	0	0	0	0	0.77	2.1
MECH5	2.08	0	0.34	0	0	0	0	0	0.77	2.1
LINR1	0.8	0	0	0	0.6	0	0	0.15	0.83	0.22
LINR2	0.8	0	0	0	0.6	0	0	0.15	1	0.22
LINR3	0.8	0	0	0	0.6	0	0	0.15	0.73	0.22
LINR4	0.8	0	0	0	0.6	0	0	0.15	0.81	0.22
NEWS1	0.55	0	0	0	0	0	0.45	0.15	0.81	0.97
OPBO1	0	0	0	0	0.6	0	0	0.15	0.5	1.04
OPBO2	0	0	0	0	0.6	0	0	0.15	0.55	1.04
OPBO3	0	0	0	0	0.6	0	0	0.15	2	1.04
OPBO4	0	0	0	0	0.6	0	0	0.15	1.32	1.04
OPBO5	0	0	0	0	0.6	0	0	0.15	1.32	1.04
OPBO6	0	0	0	0	0.6	1.19	0	0.15	0.83	1.04
OPBO7	0	0	0	0	0.6	0	0	0.15	0.27	1.04
OPBO8	0	0	0	0	0.6	0	0	0.15	0.98	1.04
OPBO9	0	0	0	0	0.6	1.19	0	0.15	0.83	1.04
OPBO10	0	0	0	0	0.6	0	0	0.15	4.1	1.04
OPBO11	0	0	0	0	0.6	0	0	0.15	0.81	1.04
OPBO12	0	0	0	0	0.6	0	0	0.15	1.6	1.04
OPBO13	0	0	0	0	0.6	0	0	0.15	0.81	1.04
OPBO14	0	0	0	0	0.6	0	0	0.15	0.81	1.04
OPBO15	0	0	0	0	0.6	0	0	0.15	0.43	1.04
OPBO16	0	0	0	0	0.6	0	0	0.15	1.55	1.04
OPBO17	0	0	0	0	0.6	0	0	0.15	0.81	1.04
OPBO18	0	0	0	0	0.6	0	0	0.15	0.81	1.04
OPBO19	0	0	0	0	0.6	0	0	0.15	0.81	1.04
OPBO20	0	0	0	0	0.6	0	0	0.15	1.23	1.04
PRWR1	0	0	0	0	0.3	0	0.3	0.15	0.56	0.52
PRWR2	0	0	0	0	0.3	0	0.3	0.15	0.81	0.52
PRWR3	0	0	0	0	0.3	0	0.3	0.15	0.81	0.52
PRWR4	0	0	0	0	0.3	0	0.3	0.15	0.81	0.52
PRWR5	0	0	0	0	0.3	0	0.3	0.15	3.3	0.52
PRWR6	0	0	0	0	0.3	0	0.3	0.15	0.63	0.52
PRWR7	0	0	0	0	0.3	0	0.3	0.15	0.57	0.52
PRWR8	0	0	0	0	0.3	0	0.3	0.15	0.78	0.52
PRWR9	0	0	0	0	0.3	0	0.3	0.15	0.7	0.52

Table 17. Production capacity in tonne for technologies in pulp and paper mills in Finland. CHEM = Sulphate pulp, CTMP = Chemi-thermomechanical pulp, LINR = Liner/Case materials, MECH = Mechanical pulp, NEWS = Newsprint, OPBO = other paper and board, PRWR = Printing and writing paper.

	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10
CHEM1	0	0	0	0	0	690,000	0	0	0	0
CHEM2	0	0	0	0	0	0	650,000	0	0	0
CHEM3	0	0	0	530,000	0	0	0	0	0	0
CHEM4	0	0	0	0	0	980,000	0	0	0	0
CHEM5	0	360,000	0	0	0	0	0	0	0	0
CHEM6	0	0	0	0	0	370,000	0	0	0	0
CHEM7	0	0	0	0	0	740,000	0	0	0	0
CHEM8	0	0	0	0	0	600,000	0	0	0	0
CHEM9	0	0	800,000	0	0	0	0	0	0	0
CTMP1	0	0	0	0	0	290,000	0	0	0	0
CTMP2	0	0	0	0	0	220,000	0	0	0	0
CTMP3	0	0	300,000	0	0	0	0	0	0	0
MECH1	590,000	0	0	0	0	0	0	0	0	0
MECH2	0	0	0	0	0	0	0	0	0	330,000
MECH3	0	0	0	0	0	450,000	0	0	0	0
MECH4	0	0	0	0	225,000	0	0	0	0	0
MECH5	375,000	0	0	0	0	0	0	0	0	0
LINR1	0	0	0	0	0	0	0	105,000	0	0
LINR2	0	0	0	0	0	300,000	0	0	0	0
LINR3	0	0	0	0	275,000	0	0	0	0	0
LINR4	0	0	0	0	0	0	0	300,000	0	0
NEWS1	0	0	0	0	0	435,000	0	0	0	0
OPBO1	0	0	200,000	0	0	0	0	0	0	0
OPBO2	0	0	0	0	0	0	0	100,000	0	0
OPBO3	0	0	0	0	0	0	100,000	0	0	0
OPBO4	0	0	0	0	0	200,000	0	0	0	0
OPBO5	0	0	0	0	0	180,000	0	0	0	0
OPBO6	0	0	0	0	0	0	0	190,000	0	0
OPBO8	375,000	0	0	0	0	0	0	0	0	0
OPBO9	0	0	0	0	0	0	0	205,000	0	0
OPBO10	0	0	0	240,000	0	0	0	0	0	0
OPBO11	0	0	0	0	0	0	0	122,000	0	0
OPBO12	0	0	0	0	0	0	0	0	0	75,000
OPBO13	0	0	0	0	0	100,000	0	0	0	0
OPBO14	0	0	0	0	100,000	0	0	0	0	0
OPBO15	0	0	0	0	0	0	0	122,000	0	0
OPBO16	0	0	0	0	0	1,095,000	0	0	0	0
OPBO17	0	0	0	0	0	270,000	0	0	0	0
OPBO18	0	0	0	0	0	220,000	0	0	0	0
OPBO19	0	0	0	0	0	0	125,000	0	0	0
OPBO20	0	0	0	0	0	0	0	0	0	22,000
OPBO21	0	0	0	0	0	0	0	285,000	0	0
PRWR1	0	0	0	0	0	0	0	0	0	735,000
PRWR2	0	1,125,000	0	0	0	0	0	0	0	0
PRWR3	0	0	0	0	285,000	0	0	0	0	0
PRWR4	1,020,000	0	0	0	0	0	0	0	0	0
PRWR5	0	0	0	0	0	0	0	100,000	0	0
PRWR6	0	0	0	1600,000	0	0	0	0	0	0
PRWR7	0	0	0	0	0	560,000	0	0	0	0
PRWR8	0	0	0	0	0	800,000	0	0	0	0
PRWR9	0	0	0	0	0	0	990,000	0	0	0

5.3.4 DENMARK

The Danish pulp production is almost negligible compared with Norwegian and especially Finnish and Swedish pulp production. However, one producer of mechanical pulp is added in the model and reference production values are based on national production statistics (FAO, 2013). Input and output relations were not available. To accommodate this, total pulpwood input in production is assumed to be 2.6 per unit mechanical pulp, which is identical to one of the Norwegian mechanical pulp production technologies. Pulpwood species used in production is allocated as proportions of harvest. Energy and labour input in Norway for mechanical pulp are assumed representative of Danish inputs. Thus, mechanical pulp labour inputs and energy inputs are averages of Norwegian mechanical pulp production data. Pulp input for production of paper for each paper technology is determined by using Swedish average input pulp values for production of papers grades. This was derived from Swedish integrated mill data where one pulp category is used to produce one paper product. Conversely, after adjusting for the trade balance of pulp to determine available quantities for production of paper, the production levels of paper required significantly more pulp input than available. Assuming the nationally reported paper production values are accurate, the explanation might be that production of pulp volumes in integrated pulp and paper mills in not reported. Given that pulpwood is needed to produce the pulp, pulpwood is added as input for paper, where the total amount of pulpwood equals the national surplus of available pulpwood, when taking into account other trade balance of pulpwood and other use designations. Recycled paper is assumed used in production of linerboard, newsprint and other paper and paperboard. The proportions of recycled paper used in production compose the total used, at reference production levels. Labour and energy inputs for paper are averages based on Swedish data (Table 14) and the input/output relations and capacities can be viewed in Table 18 and Table 19, respectively.

Table 18. Input coefficients for production of one tonne pulp or paper in Denmark. Positive values are inputs. SP = Spruce pulpwood, PP = Pine pulpwood, NCP = non-coniferous pulpwood, RCYC = recycled paper, SPECP = Sulphite and dissolving pulp, CHEM = Sulphate pulp, CTMP = Chemi-thermomechanical pulp, LINR = Liner/Case materials, MECH = Mechanical pulp, NEWS = Newsprint, OPBO = other paper and board, PRWR = Printing and writing paper.

	SP	PP	NCP	CHEM	SPECP	CTMP	MECH	RCYC	Labour	Energy
MECH1	1.29	0.60	0.70	0	0	0	0	0	1.07	1.35
LINR1	0.35	0	0	0.11	0	0	0	0.27	0.54	0.22
NEWS1	0.35	0	0	0	0	0	0.10	0.27	0.29	0.97
PRWR1	0	0	1.35	0.02	0.03	0	0.10	0	1.47	0.52
OPBO1	0.35	0	0	0.10	0	0.01	0	0.27	3.76	1.04

Table 19. Production capacity in tonne for technologies in pulp and paper mills in Denmark. MECH = Mechanical pulp, LINR = Liner/Case materials, NEWS = Newsprint, PRWR = Printing and writing paper, OPBO = other paper and board.

	D1
MECH1	4,830
LINR1	210,520
NEWS1	4,230
PRWR1	155,310
OPBO1	111,460

5.4 PAPER RECYCLING

Paper (board) recycling rates (Table 20) represent the upper bounds for use of recycled paper(board) in industrial production. Thus, the upper bound values in the model are the given rates multiplied with the consumption in the previous year. While Sweden provided product category specific recycle rates (Swedish Forest Industries Federation, 2014), Denmark (Toft, 2015), Finland (METLA, 2013) and Norway (Norwegian Environment Agency, 2013) provided aggregated recycle rates. Actual recycle rates differ for individual paper and paperboard products, but limited data availability hinders recycle rate distinction between products. In order to harmonize recycle rates between countries and differentiate between paper grades, the Swedish recycling rates are applied for the Nordic countries.

Table 20. Recycling of paper and paperboard as rates of total domestic paperboard consumption.

	Denmark	Finland	Norway	Sweden
NEWS	0.91	0.91	0.91	0.91
PRWR	0.72	0.72	0.72	0.72
LINR	0.74	0.74	0.74	0.74
OPBO	0.74	0.74	0.74	0.74

5.5 ENERGY AND LABOUR COSTS

Table 21 displays labour costs for the forest industries. While industry specific national labour cost data was available for some of the Nordic countries, generic labour costs from Eurostat are selected to avoid discrepancy between the approaches used to estimate labour costs (Eurostat, 2013b). Hence, it is assumed that labour costs in the pulp and paper industry are the same as in wood products manufacturing. Labour costs for sawnwood producers are assumed to increase if production exceeds observed reference production. The assumption is justified in that sawmills have production volume flexibility, but labour costs will increase outside of conventional working hours. For each country, a polynomial regression is fitted to three data points, where x is the percent of observed reference production while y is the labour cost. The data points represent labour costs at 0, 100 and 200% of the observed reference production. At 0 and 100% the labour costs in Table 21 are applied, while the double amount is applied at the last data point. The polynomial regression is applied in the objective function in linearized form with two piecewise line segments – one covering production from 0 to 100% (where costs are equal to the values displayed in Table 21) and the other representing increasing labour costs when these exceed 100%. Hence, the marginal labour costs for individual producers follow the trajectory of the national labour cost polynomials and depend on observed producer specific production volumes.

Table 21. Labour costs in €/hour for the pulp and paper industries and the wood products producers.

Industry	Denmark	Finland	Norway	Sweden
Pulp and paper	39.9	32	56.3	38.2
Wood products	39.9	32	56.3	38.2

Table 22 displays the electricity costs for the forest industries. Electricity costs for Norway, Sweden and Finland are from 2013 and include taxes and levies (Eurostat, 2013a). Data limitations prohibit a distinction between the pulp and paper industry and the sawnwood producers in terms of electricity costs.

Table 22. Cost of electricity in €/MWh for production in the pulp and paper industry and in the wood products industry.

Industry	Denmark	Finland	Norway	Sweden
Pulp and paper	103	73	71	67
Wood products	103	73	71	67

5.6 MAINTENANCE COSTS

The model includes maintenance costs for all production capacity. The maintenance costs equal 10% of annual capital costs for new capacity. Maintenance costs are applied for all technologies in all regions producing the products listed in Table 23.

Table 23. Investment costs for forest industry machinery (Trømborg & Sjølie, 2011). Costs are listed in €/ m^3 or €/tonne depending on product.

Product	Capital costs
Spruce sawnwood	375
Pine sawnwood	375
Non-coniferous sawnwood	375
Particle board	1,249
Fibreboard	1,249
Plywood	1,249
Mechanical pulp	524
Sulfate pulp	1,249
Chemi-thermomechanical pulp	1,249
Sulphite pulp	1,249
Newsprint	1,436
Printing and writing paper	1,436
Liner board/case materials	1,436
Other paper and paperboard	1,249

6 TRANSPORT

The transport costs between regions are based on Norwegian linear cost functions, which consist of loading costs and distance dependent cost (T. F. Bolkesjø, 2004; Trømborg & Solberg, 1996) for truck, train and ship. Costs per km and ton/m^3 are assumed to be equal in the Nordic countries. Region centres, which are considered the point of most trade in forest commodities within a given region, are used to calculate the distance between regions. For transport between two regions using truck, the loading cost is not added since loading is assumed to occur within the region of origin and is added to the roundwood price. Table 24 displays the transport costs while Table 25 displays the region centres used. Transport costs from Denmark, Finland, Norway and Sweden to the region outside the modelled countries is set to calibrate the traded amount to reflect reference net trade volume. Similarly, transport costs between regions for consumer products is subject to modification to calibrate the model.

Table 24. Costs associated with transport of forest commodities for truck, train and boat. A = loading cost in €/tonne or €/ m^3 while B = is the variable cost in €/tonne/km or €/ m^3/km.

	Truck		Train		Boat	
	A	B	A	B	A	B
Roundwood and chips	2.31	0.07	6.24	0.03	0.20	0.02
Sawnwood, particleboards and plywood	1.25	0.07	6.24	0.03	0.20	0.02
Pulp, paper and fibreboard	1.25	0.07	6.24	0.04	0.20	0.02

Table 25. Region centres for each region in the model.

Region	Centre	Region	Centre	Region	Centre	Region	Centre
N1	Sarpsborg	S1	Pitea	F1	Rovaniemi	D1	Odense
N2	Oslo	S2	Umeå	F2	Oulu		
N3	Drammen	S3	Östersund	F3	Vaasa		
N4	Skien	S4	Kramfors	F4	Jyvaskyla		
N5	Gjøvik	S5	Borlange	F5	Kuopio		
N6	Elverum	S6	Stockholm	F6	Joensuu		
N7	Kristiansand	S7	Karlstad	F7	Turku		
N8	Bergen	S8	Trollhattan	F8	Hameenlinga		
N9	Sunndalsøra	S9	Nässjö	F9	Mikkeli		
N10	Steinkjer	S10	Hässleholm	F10	Helsinki		

7 TRADE AND PRODUCT PRICES

Except for sawnwood, final product foreign trade data is derived from the FAO Statistics related to forestry production and trade (FAO, 2013). The product aggregation used by FAO differed somewhat from the one used in the model, so a re-categorization is used. The UNECE database is employed for sawnwood because it distinguishes between species (UNECE, 2012). Import, export and export price is listed in Table 26 below. Supply and demand of roundwood and wood products from/to the foreign regions are specified as constant supply curves. The reference is used to determine actual prices and quantities. Demand (and associated trade) is a decreasing function of the product price using demand and price elasticities. Roundwood supply is modelled with less price elasticity than manufactured products because of higher transport costs and hygienic issues (among others). Supply elasticity for roundwood is set to 2 and demand elasticity -2, the corresponding elasticities for manufactured products are 5 and -5, respectively. Sawlogs and pulpwood imports, exports and export prices are traded quantities in 2013 (METLA, 2013; Statistics Norway, 2013a; Swedish Forest Agency, 2014) except for Danish and Norwegian values which are from 2012 (UNECE, 2012). Since no distinction is made between pulpwood and sawlogs in the Danish and Norwegian trade data, 50% of imports and exports are assigned as pulpwood and sawlogs for Norway. For Denmark, allocation is used as a measure of mass balance to ensure full utilization of sawlogs and pulpwood. Prices of logs and pulpwood are interregional and are not displayed here (see Table 6 for prices). Domestic prices for final consumer products are set as the export prices, if there was export in 2013. In cases with no export, global average product prices are used (FAO, 2013)

Table 26. Trade values for Denmark, Finland, Norway and Sweden. EX and IM are given in 1000 m³ or tonne and represent export and import, respectively. P is the price given in €/ m³ or €/tonne and is the import price for pulpwood and sawlogs and export price for intermediate and final products. SP = Spruce pulpwood, PP = Pine pulpwood, NCP = non-coniferous pulpwood, SL = Spruce saw logs, PP = Pine saw logs, NCP = non-coniferous saw logs, SSAW = Spruce sawnwood, PSAW = Pine sawnwood, NSAW = Non-coniferous sawnwood, FIBR = fibreboard, PART = particle board, PLYW = plywood, SPECP = Sulphite and dissolving pulp, CHEM = Sulphate pulp, CTMP = Chemi-thermomechanical pulp, MECH = Mechanical pulp, LINR = Liner/Case materials, NEWS = Newsprint, OPBO = other paper and board and PRWR = Printing and writing paper.

	Denmark			Finland			Norway			Sweden		
	EX	IM	P	EX	IM	P	EX	IM	P	EX	IM	P
CHEM	0	37		2,387	482	499	217	40	550	2,658	370	603
CTMP	0	1		228	2	406	2	0	354	216	19	455
FIBR	5	156	669	47	321	378	22	188	669	0	0	
LINR	5	292	492	548	199	483	38	89	414	1,620	260	559
MECH	5	156	352	0	4		84	0	370	52	12	456
NEWS	7	131	556	225	89	462	424	111	430	1,356	42	545
NCL	158	0	108	0	108	72	0	0	120	3	20	247
NCP	62	145	41	3	4,059	46	28	215	38	9	1,676	63
NSAW	81	102	265	13	49	364	0	82		11	49	417
OPBO	102	211	664	2,661	72	891	125	194	846	4,261	549	901
PART	50	240	294	26	105	276	125	132	268	103	480	466
PL	370	0	47	283	246	111	77	9	55	164	562	84
PLYW	0	266		855	111	524	0	70		75	155	488
PP	67	15	20	324	496	52	77	9	33	208	1,876	56
PRWR	15	128	1154	6,449	102	659	461	181	566	3,291	288	1,111
PSAW	56	567	125	2,805	123	189	111	462	167	5,640	123	223
SL	401	0	47	16	135	63	28	803	54	164	562	84
SPECP	0	4		0	0		161	10	1,178	509	21	658
SP	127	67	35	67	877	47	28	803	34	208	1,876	56
SSAW	120	1217	133	2,286	180	187	364	311	161	6,612	180	214

8 CONSUMPTION OF FOREST-BASED PRODUCTS

8.1 CONSUMPTION

The national consumption of products is calculated as production – export + imports. For each final product in countries with more than one region, consumption is distributed per annum and regional consumption is thus a function of regional population size. National export prices listed in Table 26 are applied as nation-specific regional domestic prices for consumer products. In cases where there is no export price of a product listed for individual countries, the highest Nordic export price is applied. The regionalized consumption pattern is displayed in Table 27.

Table 27. Final products consumption in 1000 [tonne or m^3]. SSAW = Spruce sawnwood, PSAW = Pine sawnwood, NSAW = Non-coniferous sawnwood, FIBR = fibreboard, PART = Particle board, PLYW = Plywood, LINR = Liner/Case materials, NEWS = Newsprint, OPBO = Other paper and board, PRWR = Printing and writing paper.

	Sawnwood			Boards			Paper			
	SSAW	PSAW	NSAW	PART	PLYW	FIBR	NEWS	PRWR	LINR	OPBO
D1	1,295	604	88	536	266	156	128	268	498	221
F1	105	73	1	7	11	14	12	35	25	70
F2	278	193	4	19	30	36	32	92	67	184
F3	255	177	3	17	28	33	29	84	61	169
F4	16	11	0	1	2	2	2	5	4	10
F5	14	10	0	1	2	2	2	5	3	9
F6	275	192	4	19	30	36	31	91	66	182
F7	173	120	2	12	19	22	20	57	42	115
F8	505	352	7	35	55	65	58	167	122	335
F9	88	61	1	6	10	11	10	29	21	58
F10	911	635	12	62	99	118	104	302	219	605
N1	55	43	5	24	9	16	9	16	3	10
N2	234	184	22	104	39	68	39	69	13	43
N3	98	77	9	44	16	28	16	29	5	18
N4	55	43	5	24	9	16	9	16	3	10
N5	36	28	3	16	6	10	6	11	2	7
N6	37	29	3	17	6	11	6	11	2	7
N7	126	99	12	56	21	37	21	37	7	23
N8	119	93	11	53	20	34	20	35	6	22
N9	119	94	11	53	20	34	20	35	6	22
N10	72	57	7	32	12	21	12	21	4	13
S1	125	50	1	30	6	10	14	7	11	29
S2	12	5	0	3	1	1	1	1	1	3
S3	63	25	1	15	3	5	7	3	6	15
S4	121	48	1	29	5	10	13	6	11	28
S5	272	108	3	66	12	22	29	14	24	64
S6	1,153	456	12	279	51	92	125	61	101	271
S7	134	53	1	32	6	11	14	7	12	31
S8	721	285	7	175	32	58	78	38	63	169
S9	321	127	3	78	14	26	35	17	28	75
S10	851	337	9	206	37	68	92	45	75	200

8.1.1 ELASTICITIES OF DEMAND

Demand elasticities used included GDP elasticities and price elasticities. The demand price elasticities for final products for markets are based on econometric studies for developed countries (Buongiorno, Zhu, Turner, & Tomberlin, 2003), while demand elasticities for intermediates are based on data applied in a Norwegian model (Trømborg & Sjølie, 2011). The GDP elasticities displayed in Table 28 are applied for all countries in the model.

Table 28. GDP and price elasticities of final ("Spruce sawnwood" to "other paper and paperboard") and intermediate products.

Product	Elasticity	
	Price	GDP
Spruce sawnwood	-0.24	0.78
Pine Sawnwood	-0.24	0.78
Non-coniferous sawnwood	-0.53	0.65
Fibreboard	-0.3	1.06
Plywood	-0.37	0.95
Particle board	-0.17	1.06
Newsprint	-0.6	1.04
Printing and writing paper	-0.6	1.27
Linerboard	-0.38	1.02
Other paper and paperboard	-0.38	1.02
Sulfite and dissolving pulp	-0.5	
Sulfate pulp	-0.5	
Mechanical pulp	-0.5	
Chemi-thermomechanical pulp	-0.5	

GDP growth is set using the IPCC B2 scenario for medium economic growth in western countries, which equals 1.3% from 2013 to 2020 and 0.8% beyond (IPCC, 2007). Since Denmark, Finland and Sweden do not provide regional/municipality level population growth estimates, GDP growth is assumed equal in each region. While Statistics Norway (Statistics Norway, 2014) provides regional population growth estimates these were ignored to permit a more harmonized approach across the all regions.

9 BIOHEAT

9.1 SPACE-BASED HEATING

Table 29 displays the feedstock input in production of space-based heating while Table 30 displays the demand for space-based heating. Data for production of space heating based on firewood is derived from commercial and non-commercial firewood consumption (DCE, 2015). Conversely, harvest data used for Denmark only accounted for forests with areas above 0.5 hectares and only accounted for a small proportion of forests in the 0.5 to 1 ha area (Statistics Denmark, 2013). Hence, there is a large discrepancy between estimated harvested pulpwood for firewood and actual firewood use in wood stoves, because a large proportion of firewood used in Denmark is derived from small private forests. To accommodate this, only 17.2 percent, which represents the production from Danish forests (Hansen, 2015), of actual heat produced from firewood stoves is included as the reference value. The firewood energy recovery rate is set to 70%. Finnish data for production of space heating was available at regional scale, based on small scale combustion of wood in 2013 (METLA, 2014). Data for firewood consumption in households was available for Norway at regional scale (Statistics Norway, 2011). Conversely, the date represents consumption in 2010, and 2013 national consumption figures represent significantly different consumption patterns (Statistics Norway, 2013c). To accommodate the difference, national consumption of firewood in 2013 is used to determine regional consumption based on the regional consumption distribution in 2010. Pellets consumption in Norway is assumed to only occur in households in the model and is estimated to amount to 66,188 tonnes at national consumption level (NOBIO, 2012). National consumption is distributed regionally following the firewood consumption distribution. Swedish space-based heating data is based on wood fuel use in one- and two household dwellings (Swedish Forest Agency, 2014). Use of firewood, pellets and chips is regionalized proportional to regional population densities.

Table 29. Feedstock input in m^3 or in tonne for producing exactly 1 MWh space-based heating. Chips is given in loose volume.

		Firewood	Pellets	Chips
Denmark	Stove1	1.65		
	Stove2		1.11	
Finland	Stove1	1.85		
Norway	Stove1	1.85		
	Stove2		1.11	
Sweden	Stove1	1.85		
	Stove2			1.25
	Stove3		1.11	

Table 30. Consumption of space-based heating in 1000 MWh.

D1	3890	F1	159	N1	422	S1	146
		F2	422	N2	641	S2	14
		F3	387	N3	422	S3	74
		F4	24	N4	379	S4	141
		F5	22	N5	713	S5	317
		F6	418	N6	480	S6	1,343
		F7	262	N7	670	S7	156
		F8	767	N8	641	S8	840
		F9	133	N9	874	S9	373
		F10	1,385	N10	975	S10	991

9.2 HYDRONIC HEATING

Production values in 2013 formed the basis for the reference values in Denmark (DCE, 2015). Fuels other than forest-based biomass are not included, which explains why the total production is significantly lower than national estimates. The input quantities are based on national energy densities for fuels (DCE, 2015) assuming a 90% energy conversion efficiency in production. Losses in the grid are ignored, because they do not affect the wood material balance. The capacity for production of heat in Sweden is based on data provided by the Swedish district heating association (Sjostrom & Khodoyari, 2014). For each production unit, energy output per fuel input is listed. Because it would be too cumbersome for modelling purposes to specify a technology for each production unit, a regional aggregation is employed. In each region for district heating technologies, the heat output per fuel type is summed, multiplied by the average energy conversion efficiency for all district heating producers, and assumed to compose one technology. Capacity for each fuel in each region is the sum of production using the respective fuels. CHP heat production is also included without modelling electricity production. Rather than specifying one technology per fuel type, as is the case with district heating, one technology for CHP production of heat is specified using the proportional average input of forest biofuels used in production. The production in a given Swedish region is the sum of all forest biofuel use, multiplied by the average energy efficiency for all CHP forest bioheat producers. An identical approach is used for Finland using Finnish Energy Industries data (Finnish Energy Industries, 2013). See Table 31 and Table 32 for the input/output relations and the regional consumption, respectively. The Norwegian district heating data in Table 31 and Table 32 are based on values from an existing Norwegian partial equilibrium model (Trømborg & Sjølie, 2011), updated to 2013 values. The regional production in 2010 is used to determine the proportional allocation of national production values in 2013 (Statistics Norway, 2013b).

Table 31. Fuel in m³ or tonne inputs per MWh delivered hydronic heating. Chips is given in loose volume.

		Pellets	Chips	Dust	Bark
Denmark	CHP1	0.34	0.92	0.06	0.06
	DH1		1.28		
	DH2	1.18			
	DH3			1.18	
	DH4				1.38
Finland	CHP1	0.03	1.27	0.54	
	DH1		1.28		
	DH2			1.18	
	DH3	1.18			
Norway	DH1		1.28		
	DH2	1.18			
	DH3		1.25		
Sweden	CHP1	0.07	1.10	0.03	0.1
	DH1	1.18			
	DH2		1.28		
	DH3			1.18	
	DH4				1.38

Consumption of heat from district and central heating as well as heating from CHPs is based on data from the Swedish district heating association (Sjostrom & Khodoyari, 2014), Danish Energy Agency (DCE, 2015), Finnish Energy Industries (Finnish Energy Industries, 2013) and from the Norwegian district heating association (Trømborg & Sjølie, 2011). Again, it should be noted that the total reflects the proportion produced with forest-based biomass. The data is presented in Table 32.

Table 32. Consumption of hydronic heating using forest biomass in 1000 MWh. Reference year is 2014 for Sweden and Finland and 2013 for Norway.

D1	5,751	F1	376	N1	2	S1	275
		F2	714	N2	431	S2	1,174
		F3	288	N3	276	S3	53
		F4	129	N4	44	S4	253
		F5	593	N5	78	S5	1,187
		F6	954	N6	24	S6	6,813
		F7	701	N7	15	S7	381
		F8	1,217	N8	6	S8	2,561
		F9	493	N9	56	S9	2,291
		F10	531	N10	75	S10	2,432
Total	**5,751**		**5,996**		**1,007**		**17,420**

10 DATA QUALITY CONSIDERATIONS

A review of the data used in NFSM reveals data representativeness issues and data. Data is in many cases heterogeneous between the Nordic countries and the availability of data at regional scale is often limited or lacks the level of detail needed to be used without modification in the model. Data harmonization between the Nordic countries and data "gap-filling", when data was unavailable was a necessary consequence. An example is the lack of distinction between harvested species and assortments at regional scale for Sweden; another is limited availability of regional forest-industry product consumption data. Hence, there are cases where access to better data could potentially increase model-simulation representativeness. Data detail often fitted well with the scale of NFSM because simplifications in large-scale models are often welcomed. An example is the FAO reporting of trade between countries, where a simplified aggregation of pulp and paper grades into eight manageable categories is applied. The benefits of a few categories of pulp and paper products as opposed to a few thousand, which is the real case, is not just for end-user manageability – it also reduces the number of single variables generated during model execution which reduces compute time. The aggregation of products into product categories has disadvantages. Some categories will be more homogenous than others will and will therefore be better represented in the model. Newsprint is an example of a homogenous category while "other paper and paperboard" represents a diverse category of paper products which can be distinctly different in composition, method of production and production costs. They may also fetch noticeably different market prices. The aggregation of "other paper and paperboard" necessitates a shared market price, which therefore favours production lines with lower marginal production costs in the equilibrium solution. Production of comparatively high quality "other paper and paperboard" is therefore disfavoured. However, model calibration of individual production line costs aids in harmonizing this inequality. A big model uncertainty stems from the material balances of the pulp and paper production lines. This is especially true for Danish, Finnish and Swedish pulp and paper producers who, in many cases, did not share such information. As an approximation, pulpwood use from Norwegian pulp and paper production lines are assumed representative when data from the actual producers was unavailable. Hence, it is assumed that pulpwood input in production of pulp and paper were homogenous throughout the Nordic countries. Using a combination of material balances from individual and from Norwegian producers, estimated regional pulpwood use in production of pulp and paper in Sweden and Finland was compared to the total regional pulpwood consumption. These values were found to be quite similar (within 5% and 11% deviation from the actual pulpwood used, respectively), which may suggest that pulpwood use for the various categories of pulp and paper are homogenous. However, inputs and costs in production of pulp and paper on plant level have a rather weak empirical basis and are associated with higher uncertainty than other data. Interpretation of results related to techno-economic aspects of the pulp and paper industries should be handled mindfully and this is an area for future improvement of the model. Similar assumptions made for material balances in solid wood products production are more justified in that solid wood products production (especially sawnwood production) is comparatively homogenous which increases data reliability. The approach to determine the input coefficients for production of both pulp and paper as well as solid wood products does not permit distinguishing between individual producers in terms of profitability. In practice, this limits the application of the model to studies, which assess industry competitiveness at sector level and not at producer level. Hence, access to actual techno-economic data from individual producers could permit enriched studies but will require robust cooperation with industry partners. With more resources, the transport cost estimates could be significantly improved. The current approach, which relies on dated Norwegian estimates using a loading and a distant dependant cost, ignores the infrastructural road differences as well as wage compensation rate differences between the Nordic countries, which may have large implications for model transport dynamics. In addition, the method employed ignores economies of scale benefits associated with increasing loading volume. The regionalization approach also alters the effect of transport costs because it alters the proximity to market and feedstocks for individual producers. Within-region transport dynamics are not captured because the model ignores within-region transport costs. Between-region transport costs are constant per unit feedstock or final product, which may underestimate or overestimate transport costs. A future modification of the model would benefit significantly from addressing these issues. In sum, there is room for improvement of the model given additional time and resources.

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